Shade net studies on two Japanese plum cultivars *(Prunus salicina* Lindl.)

By

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DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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SUMMARY

South Africa is one of the major exporters of Japanese plums (*Prunus salicina* Lindl.) to Europe and the United Kingdom. The demand for top quality fruit upon purchase drives farmers to optimize fruit production practices. Protective nets have gained tremendous popularity among fruit growers as means of total crop protection against meteorological hazards, as well as small pests and even theft. The most common net colors used in the Western Cape are white, and closed on the sides with green nets. Reduced light intensity reduces direct radiation and fruit surface temperatures and therefore heat and sunburn damage, although percentages of sunburnt fruit was low in our trials. Shade nets reduced the average air temperature by ca. 3 °C and soil temperatures by ca. 1 to 3 °C. Reduced air movement significantly reduced wind damage to ‘Midnight Gold’ plums. Diurnal temperature fluctuations were less extreme under nets, and relative humidity was on average 5 to 10% higher compared to the open. The improved microclimate under nets tends to benefit water relations, which increases fruit size as well as vegetative growth, thus yield may be compromised. The yield was unaffected in the first season of ‘Larry Ann’, but yield efficiency decreased under the 20% crystal white shade nets, while in the second season yield increased under nets. In ‘Midnight Gold’ the yield and yield efficiency was unaffected by the nets in the first season and decreased under nets in the second season. ‘Larry Ann’ fruit weight decreased under nets in the first season only. Fruit from under nets were generally firmer at harvest, but overall differences were horticulturally insignificant. Fruit color and maturity indices were less advanced under nets with fruit being slightly lighter and duller in color, however after cold storage differences were generally horticulturally insignificant. The occurrence of broken stones under nets were often higher due to increased fruit diameter, but differences between seasons and cultivars were more prominent, while internal disorders were greater in one season compared to the other. In the plant growth regulator (PGR) trials, vegetative pruning requirements were unaffected, while foliar applications of paclobutrazol reduced hand thinning and yield of ‘Larry Ann’ and increased fruit size after all three PGR applications. In ‘Midnight Gold’, foliar applications of prohexadione-calcium reduce the fruitlet thinning requirements and increased the yield and size of fruit, while soil PGR treatments reduced summer pruning more effectively than the remaining treatments. The PGRs were less efficient in controlling vegetative growth in both cultivars, while the effective fruit thinning was an interesting side effect.

OPSOMMING

Skadunetstudies op twee Japannese pruimkultivars *(Prunus salicina* Lindl.*)*

Suid-Afrika is een van die grootste uitvoerders van Japanse pruime (Prunus salicina Lindl.) na Europa en die Verenigde Koninkryk. Die vraag na topgehalte vrugte by aankoop dryf boere daartoe om die produksiepraktyke van vrugte te optimaliseer. Beskermingsnette het geweldig gewild geword onder vrugtekwekers as 'n totale gewasbeskerming teen meteorologiese gevare, asook klein plae en selfs diefstal. Die mees algemene netkleure wat in die Wes-Kaap gebruik word, is plat wit nette aan die sykante toegemaak met groen nette. Verlaagde ligintensiteit verminder direkte straling en vrugtemperature op die vrugte en dus skade aan hitte en sonbrand, alhoewel die persentasie sonverbrande vrugte in ons proewe laag was. Skadunette het die gemiddelde lugtemperatuur met ca. 3 °C en grondtemperature met ongeveer 1 tot 3 °C. Die verminderde lugbeweging het windskade aan 'Midnight Gold' pruime aansienlik verminder. Die skommelinge van die dag in die temperatuur was minder ekstrem onder nette, en die relatiewe humiditeit was gemiddeld 5 tot 10% hoër in vergelyking met die oop gebied. Die verbeterde mikroklimaat onder nette is geneig om waterverhoudings te bevoordeel, wat die vruggrootte sowel as die vegetatiewe groei verhoog, en die opbrengs kan dus benadeel word. Die opbrengs is nie beïnvloed in die eerste seisoen van 'Larry Ann' nie, maar die opbrengsdoeltreffendheid het afgeneem onder die kristalwit skadunette van 20%, terwyl die opbrengs in die tweede seisoen onder nette toegeneem het. In 'Midnight Gold' is die opbrengs en doeltreffendheid in die eerste seisoen nie beïnvloed deur die nette nie en het dit in die tweede seisoen afgeneem onder die nette. Die 'Larry Ann'-vrugte het slegs in die eerste seisoen onder nette afgeneem. Vrugte onder die nette was oor die algemeen stewiger met die oes, maar die totale verskille was in die tuinbou onbeduidend. Vrugtekleur en volwassenheidsindekse was minder gevorderd onder nette, met vrugte effens ligter en dowwer van kleur, maar na koelopbergingsverskille was dit oor die algemeen onbeduidend in die tuinbou. Die voorkoms van gebreekte klippe onder nette was dikwels hoër as gevolg van 'n verhoogde vrugdeursnee, maar die verskille tussen seisoene en kultivars was meer prominent, terwyl interne versteurings groter was in die een seisoen in vergelyking met die ander. In die toetse vir plantgroeireguleerders (PGR) is vegetatiewe snoeibehoeftes nie beïnvloed nie, terwyl blaartoepassings van paclobutrazol die dunner en opbrengs van 'Larry Ann' verminder en die vruggrootte na al drie PGR-toedienings verhoog het. In 'Midnight Gold' verminder blaartoedienings van prohexadion-kalsium die benodigdheid vir die uitbrei van vrugte en

verhoog die opbrengs en grootte van vrugte, terwyl grond-PGR-behandelings somersnoei effektiewelik verminder as die oorblywende behandelings. Die PGR's was minder doeltreffend in die beheer van vegetatiewe groei in albei kultivars, terwyl die effektiewe uitdunning van vrugte 'n interessante newe-effek was.

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DEDICATION

I would like to dedicate this work to Valeska.

NOTE

This thesis is a compilation of research chapters, starting with a literature review, followed by three research papers. Each paper was prepared as a scientific paper for submission to the journal *HortScience*. The language option used for the thesis is therefore English (United States). Repetition or duplication between papers might be necessary.

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GENERAL INTRODUCTION

In the plum industry, only high-quality fruit can ensure continuous demand and thus a good return income to the grower (Basile et al., 2012; Hartmann and Neumüller, 2009). Class 1 or AAA graded fruit are blemish-free, large and evenly sized within a consignment and of similar maturity. The total yield of a stone fruit orchard is dependent on numerous factors, and one of the most important ones is the sensitivity of the flowers to cool weather conditions at bloom time. Japanese plums are primarily cultivated in warmer regions as they have a low chilling requirement and are sensitive to winter and spring frost. The trees also flower early in the season and set high numbers of fruit if not thinned. Most Japanese plum cultivars are self-infertile and require compatible cross-pollinators to set fruit (Hartmann and Neumüller, 2009).

Various environmental and cultural practices influence fruit quality and tree productivity. Through the use of technologies such as shade nets, the growing environment can be manipulated to a certain extent to suit the crop and increase the returns (Minas et al., 2018). The climate in the Western Cape province of South Africa is considered to be a Mediterranean-type climate, with hot and dry summers and cool and wet winters. Summer and winter minimum and maximum temperatures are ca. 9.3 and 41.3 ºC, and 0.8 and 28.9 ºC, respectively (Midgley et al., 2016). Due to the changes in global climates, Mediterranean-type climatic regions are expected to have decreased rainfall, elevated temperatures and more frequent intense heat waves (Midgley et al., 2016). Hail is relatively rare in the Western Cape Province, but there have been severe localized hailstorms that have wiped out the entire crop of farms in the Witzenburg, Ceres and Koue Bokkeveld regions (Midgely et al., 2016). The Western Cape often has strong winds and high irradiation causing damage to fruit and trees during the growing seasons. In principle, climatic extremes affect fruit by increasing sunburn and wind damage, which then decreases the market value to varying degrees. With regards to Japanese plum production, plums are primarily cultivated in warmer regions around the world because they have a low chilling requirement and the blossoms, which open early in the season, are sensitive to winter and spring frost (Haartman and Neumüller, 2009). Therefore, small manipulations of the orchard environment in favor of the trees may produce substantial positive results.

Originally, nets were used to protect fruit orchards from hail, and soon additional benefits such as increased fruit size or marketable yield were observed, thus the use of nets increased (Kalcsits et al., 2017, Solomakhin and Blanke, 2010; Tinyane et al., 2018). One of the negative effects nets have on crops is an increase in vegetative growth that often compromises reproductive growth. The increased vegetative growth was found to be due to factors relating to a more favorable growing condition under nets (Amarante et al., 2011; Basile et al., 2012; Murray et al., 2005). The ideal growing environment for most crop types would be similar to that of a greenhouse, where external disturbances and harsh environmental conditions are minimized. Nets reduce wind speed, increase relative humidity (RH), decrease soil water evaporation, decreased temperature fluctuations and decrease irradiance levels; these factors may make photosynthesis more efficient (Amarante et al., 2011; Basile et al., 2012; Girona et al., 2015). The net photosynthetic intensity of fruit trees increases proportionally with temperatures up to 30 ºC and then decreases above 30 ºC (Cosmulescu et al., 2010). Light intensity in terms of the photosynthetic active radiation (PAR) also has saturation limits in most plants, and so the use of shade nets may delay or even prevent photosynthetic leaves from reaching saturation limits and thus photosynthesis may continue throughout the day (Cosmulescu et al., 2010). As temperatures reach well above 30 ºC in the summer in the Western Cape, trees are more prone to stress.

In this study, the aim was to investigate the effects of shade nets on Japanese plum fruit quality. We also wanted to evaluate the effects nets would have on the efficacy of commonly used plant growth regulators (PGRs) used to manage vegetative growth, as spray coverage and chemical absorption is improved under nets (Middleton and McWaters, 2000).

In the literature review, studies on other fruit types as well as plums were included, as the literature on plums is limited. To understand the effects of different types of shade nets on the microenvironment, it is necessary to take note of the changes in light under nets and the effective wavelength and direction of light. This results in altered tree physiology and thus growth and development. The review also included research on commonly used PGRs, such as paclobutrazol (PBZ), uniconazole (UCZ) and prohexadione-calcium (ProCa) to control vegetative growth, including the chemistry and the effects on tree physiology and growth. (Rademacher, 2004). Paclobutrazol and UCZ are older chemicals, and thus the majority of the research is relatively old compared to ProCa, which is the latest option growers can use for vegetative growth (Rademacher, 2004).

The research is reported in three research papers. In Paper 1, the effects of a 20% crystal white shade net on the yield and fruit quality of two plum cultivars ‘Larry Ann’ and ‘Midnight Gold’ is compared to non-covered control trees. Fruit quality at commercial harvest is determined by looking at fruit size, maturity, and appearance, as well as the postharvest quality. In Paper 2, the same two cultivars growing under nets were used. Three PGRs applied, either as soil or foliar treatments were evaluated for their efficacy to control one-year-old shoot extension growth. Fruit quality and yield were assessed. The effect on shoot extension growth was estimated by determining the PGR effect on the summer and winter pruning intensity required. Paper 3 reports on a questionnaire that was sent out to four Japanese plum growers in the Western Cape region who are currently growing plums under nets. The results in the type of net used, their construction, and the various changes in management practices that are required are summarized.

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LITERATURE REVIEW: Effect of Protective Netting on Japanese Plum Fruit Quality and Tree Productivity

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Introduction

The Japanese plum (*Prunus salicina* Lindl.) originated in China and has been cultivated across the globe for several thousand years (Erogul and Sen, 2015). Production statistics for 2017 show that South Africa has a total of 2231 stone fruit producers, creating a turnover of R2,7 billion (Hortgro, 2017). Nearly 75% of plums are exported, with Europe the major destination receiving 45% of exports (Hortgro, 2017). South Africa is ranked as the 21st largest plum producer worldwide, but the third-largest in the Southern Hemisphere behind Chile and Argentina (Hortgro, 2017), and in terms of export, South Africa is the second-largest exporter of fresh plums behind Chile. Plum production, in total hectares (ha) planted in South Africa, is relatively low with 5248 ha compared to other deciduous fruit, i.e. grapes (table and dry) 25 811, apples 24 156 ha, pears 12 265 ha and peaches (cling and desert) 9974 ha (Hortgro, 2017). The largest production area for plums in South Africa is in the Klein Karoo in the Western Cape province, with a total of 1526 ha (Hortgro, 2017).

Together with yield, fruit quality, both internal and external, is a priority in fruit production. Low-quality fruit results in major financial losses to the producer. Consumers first purchase with their eyes, making visual quality the main driving factor (Moser et al., 2011). Therefore, one of the main reason's fruits are discarded at packhouses is due to physical external damage such as sunburn (Dussi et al., 2005). However, consumers have also become more aware of the health benefits of fruits and vegetables due to supporting clinical studies on antioxidant and phenol content in fruits. The concentrations of these molecules in the fruit are affected by various preharvest and environmental factors (Basile et al., 2012). However, consumer studies have shown that total soluble solids (TSS) concentration and total acidity (TA) still play the major roles in favor preferences (Louw and Theron, 2010), and both visual and organoleptic characters of fruit drive consumption of fruit.

Production of high-quality fruit starts in the orchard with the implementation of sound production practices. Among these are the correct cultivar and rootstock choice for the site, high-density planting systems with relevant pruning strategies, fertilizer and irrigation practices, anti-hail or shade nets (protective netting) and the use of plant growth regulators (PGRs). Preharvest cultural practices influence the growth and development of the trees, and thus their productivity (Zhang and Whiting, 2013). As fruit set in stone fruit is often very heavy, fruitlet thinning is an important and standard practice in the successful production of high-quality fruit. Maximum yield does not always equal maximum profit, but producing adequate yields and maximizing class 1 fruit may do so (Moser et al., 2011; Zhang and Whiting, 2013).

Stone fruit generally has a short post-harvest life compared to other deciduous fruit and can quickly pass from the ideal eating quality to being overripe, with decay setting in. Japanese plums tend to readily lose water and shrivel under poor storage conditions as most cultivars are sensitive to long cold-storage conditions and are also easily damaged by pathogens (Crisosto et al., 2008; Jooste, 2012). Also, plums can become unmarketable due to chilling injuries (CI), i.e. internal browning, gel breakdown and aerated tissues (Velardo-Micharet et al., 2017). The harvest maturity of stone fruit determines their eating quality, susceptibility to mechanical damage, post-harvest performance, and potential shelf life. Fruit that is harvested immature are easier to handle but will be incapable of ripening to their full potential, whereas fruit harvested mature will not withstand post-harvest handling, distribution, and storage (Crisosto et al., 2008). Pruning improves light distribution to all parts of the canopy and allows a more even maturation of fruit in all parts of the canopy (Crisosto et al., 2008). Together with correct pruning, the use of protective netting may increase the scattering of light under nets, resulting in better light penetration to the inner parts of the canopy (Basile et al., 2012, Kalcsits et al., 2017).

Protective nets are relatively new in the South African deciduous fruit industry, and even more so on stone fruit. The use of protective nets over crops is common in the vegetable, cut flower, and nursery industries, but only in the early 1990s did covering fruit tree orchards start. Nets reduce the incoming photosynthetically active radiation (PAR), which results in reduced physical damage to fruit and trees, and in some cases improves overall fruit quality (Lee et al., 2015; Murray et al., 2005). Murray et al. (2005) found that branches of plum trees subjected to 20 and 50% shading treatments experienced a more favorable water status, with higher midday xylem water potentials than branches exposed to full sun that had lower xylem water potential, thus allowing more rapid increase in fruit volume under nets (Lee et al., 2015; Murray et al., 2005). In addition, pollination, and thus fertilization may be affected under nets due to reduced bee activity, and more importantly due to the alteration of spectral quality and level of irradiance affecting return bloom and or fruit set (Basile et al., 2014; Solomakhin and Blanke, 2008).

The changes in vegetative growth under nets can be explained by the changes in total solar radiation reaching the canopy, which results in altered leaf gas-exchange patterns, leaf morphology and source-sink relationships (Dussi et al., 2005; Lee et al., 2015; Mupambi et al., 2018). The changes in vegetative growth range from positive results, such as increased stomatal conductance under shade nets due to decreased evapotranspiration (Lee et al., 2015), an increase in vegetative shoot growth in younger trees enabling quicker filling of allotted spaces, to some negative aspects that may occur in older orchards such as increased vigor and apical dominance (Basile et al., 2012; Kalcsits et al., 2017).

Proper tree management requires a balance between vegetative and reproductive growth to be maintained (Rademacher, 2004). With the altered microclimate under nets, the efficacy of commonly used PGRs needs to be evaluated. The most common PGRs used on deciduous trees for growth control are gibberellin biosynthesis inhibitors, e.g. paclobutrazol (PBZ), uniconazole (UCZ), or prohexadione-calcium (ProCa). These act by inhibiting gibberellin biosynthesis, which inhibits shoot elongation (Rademacher, 2004). In addition, fertilization of the ovule may be prevented with GA-biosynthesis inhibitors as GA is directly involved in pollen tube growth within the style (Raz et al., 2010; Stern et al., 2009). Plant productivity should not be reduced with the use of PGRs, thus timing, application rates and method of application are all important considerations (Rademacher, 2000). Fruit trees that are kept more compact through the use of PGRs reduce the cost of pruning and maintain a more favorable vegetative and reproductive ratio (Rademacher, 2000). Excessive shoot growth has been shown to reduce return bloom in bearing apple trees (Solomakhin and Blanke, 2008), and in younger trees reduces the flowering and thus fruiting (Rademacher, 2004) as well as increase pruning costs, thus reducing shoot growth would be of relevance to plums as no dwarfing rootstocks are currently available, and production costs can be lowered overall (Lurie et al., 1997; Smit, 2002).

One of the main reasons protective netting is used is to protect the crop underneath from environmental damage, predominantly hail, wind and high radiation (Castellano et al., 2008; Kalcsits et al., 2017). Protective nets change the underlying microclimate, resulting in changes to both fruit and tree growth. Positive results have been found on deciduous fruit grown under nets such as improved quality in apples (Dussi et al., 2005; Kalcsits et al., 2017; Solomakhin and Blanke, 2010), peaches (Girona et al., 2012), mandarin (Lee et al., 2015), kiwi (Basile et al., 2012), and plums (in which only a selected number of branches were covered with shade nets) (Murray et al., 2005). The modified microenvironment under nets tends to enhance vegetative growth which in turn may affect the efficacy of PGRs applied to manage vegetative and reproductive balance, but on the other hand, it may enhance uptake of PGRs by allowing a longer leaf wetness period and or better spray coverage with less drift, which are important factors in proper tree management (Kalcsits et al., 2017; Middleton and McWaters, 2002; Rademacher, 2004).

In this literature review, the importance of the Japanese plum, to South Africa as a producer, will be briefly reviewed followed by the effects of shade nets on crops and microenvironment. Lastly, three PGRs commonly used on deciduous fruit will be reviewed as a means to control vegetative growth in plum trees.

Plum fruit quality characteristics

Measuring quality. The word "quality" is defined as '*the standard of something as measured against other things of a similar kind; or the degree of excellence of something*' (The Oxford English Dictionary, 2018). Several parameters define fruit quality, and the overall storability, consumer satisfaction and economic return of the fruit. Fruit quality parameters include numerous internal factors such as texture, flavor and nutritional value, and external factors such as appearance, and aroma (Moser et al., 2011). Plum fruit quality parameters are determined as follows: fruit color is measured using a colorimeter in research practices, and reported as hue angle, lightness, and chroma, or commercially it is subjectively assesses utilizing a color chart designed for a specific cultivar. Firmness is determined on peeled opposite cheeks of the fruit using a penetrometer fitted with an 11 mm tip for plums in South Africa. Internal measurements are usually done destructively by cutting open fruit to assess for broken stones and visually inspecting for internal disorders. Slices of fruit are cut from each side and juiced for total soluble solids (TSS) and total acidity (TA) analysis. Total acidity is determined through titration, while TSS is measured using a refractometer.

Industry and consumer standards. The highest returns for fruit come from large, blemish-free fruit with excellent internal and external attributes (Camelo, 2004). Non-uniform consignments, such as fruit varying in maturity or size, are often downgraded, compromising retailer and consumer satisfaction (Murray et al., 2005). The growing demand for high-quality fruit among consumers, both internal and external quality drives the decision to purchase a specific fruit (Camelo, 2004), whilst the eating quality of plums is influenced by both aroma and flavor, involving non-volatiles such as sugars and acids, and various volatile aromatic compounds (Louw and Theron, 2012). These compounds, together with the physical structure of plum fruit, may be influenced by both pre- and post-harvest practices (Louw and Theron, 2012). When protective nets are used to improve fruit quality, the result should be fruit with fewer disorders, good storability, good appearance, i.e., high-value fruit that justify the costs of netting structures (Štampar et al., 2001; Stamps, 2009; Tinyane et al., 2018)

Pre-harvest factors affecting fruit quality

Orchard management practices. Manipulating the source-sink balance in fruit trees is possibly one of the greatest contributors to improving fruit quality (Zhang and Whiting, 2013). Lee et al. (2015)

noted that fruit quality and shelf-life are ultimately related to preharvest factors, which may be manipulated to improve quality and tree productivity. A study done on sweet cherries grafted onto precocious dwarfing rootstocks to manipulate crop load by altering the vegetative versus reproductive sink balance, together with the use of PGRs, improved overall fruit quality (Zhang and Whiting, 2013). They reported that by reducing inter-fruit carbohydrate and source competition, intra-fruit carbon partitioning and fruit quality was altered in sweet cherry, resulting in larger fruit of better quality. Erogul and Sen (2015) noted that balancing the fruit load with tree size and leaf area maintains consistent yields and maximizes fruit growth. Fruit thinning, vegetative growth control, irrigation, and fertilization practices should all be adjusted accordingly with proper orchard management to produce an optimal yield (Erogul and Sen, 2015; Rademacher, 2004).

Maturity and ripening. Plums are classified as soft fruit and therefore do not store well for long periods (Usenik et al., 2008). Harvest maturity plays an important role in the ripening and storability of plums, as well as controlling other quality parameters (Louw and Theron, 2012; Usenik et al., 2008). Two or three harvests are recommended for plums, but often orchards are stripped all at once resulting in different maturities that persist post-harvest (Murray et al., 2005). Nets may delay fruit maturity by altering quality parameters (Solomakhin and Blanke, 2008) such as firmness, weight, and appearance, and non-volatiles such as the TSS/TA components are used to determine the harvest maturity of plums (Louw and Theron, 2012). Plums are deemed ripe when ground color has changed from green to yellow, and a red top color may develop (Usenik et al., 2008) while having an optimum firmness between 7.0 and 10.5 kg, and a 13.0% TSS, as determined for cultivar 'Sun Supreme™' (De Kock and Buchanan, 2010). TSS concentration and TA greatly influence the palatability of fruit. By measuring the TSS and TA at harvest, the maturity, or ripeness, of the plum fruit can be determined. Measurements before and after cold storage as well as during storage intervals will also give an indication of fruit maturity, and storage life of the fruit (Usenik et al., 2008).

Murray et al. (2005) evaluated factors contributing to postharvest fruit quality of 'Laetitia' and 'Songold' plums subjected to three shading treatments (20, 50 and 80% black shade net) compared to a non-shaded control. The different canopy light environments contributed to the harvest maturity of both plum cultivars, where shaded fruit was less mature at harvest compared to control fruit. Increased exposure to light had positive effects on fruit size, TSS and red color development, resulting in sun-exposed fruit being more mature than shaded fruit; therefore the main effects of shade on fruit quality was attributed to delayed maturity when all fruits are harvested at once (Murray et al., 2005).

Light quality and quantity for fruit development

Sunlight is thus required for fruit color development, particularly towards the final stages of fruit development (Murray et al., 2005; Usenik et al., 2009). Anthocyanin synthesis in apples increases towards harvest maturity (Steyn et al., 2005), and according to Murray et al. (2005) at least 70% light is needed for optimal red color development in plums. In apples, anthocyanins appear under high light stress conditions and protect fruit peels by trapping light in the chlorophyll absorption gap (green-orange spectrum), and when combined with cool temperatures and high light, peels rapidly accumulated anthocyanin pigments. Usenik et al. (2009) investigated the anthocyanin concentration in different European plums and the influence of maturity determining peel color, and found that chroma measurements and hue angle of partially ripe plums were always higher than ripe plums, and as plums ripened hue angle decreased (became more purple/red in those that accumulate anthocyanins). However, the evolution of color was found to be cultivar dependent, and the parameters of color, such as hue angle, lightness, and chroma, were always correlated with one another due to varying anthocyanin levels of different cultivars. Usenik et al. (2009) also found that the ratios of various anthocyanins changed as the fruit ripened, and levels of total and individual anthocyanins showed a weak correlation.

Sunlight contains photons of different wavelengths that plants utilize to regulate and stimulate different processes (Taiz et al., 2015a). Wavelengths may be altered through uses of photoselective shade nets (Basile et al., 2012; Solomakhin and Blake, 2008), changing the quality and or quantity of light. The effects of nets on color development will be discussed under the heading 'Color development' in a later section on 'Protective nets effects on external fruit quality'.

Type of agricultural nets available.

Net types. There are numerous types of plastic nets available for use in agriculture. The structural properties are based on the kind of plastic, the tread or weave type or pattern, and the shape and dimension of fibers. The physical properties of nets, such as the material color, shading factor, durability, air permeability, and mechanical properties, influence the shading effect, and nets may be custom made to give a specific shading response (Castellano et al., 2008). Woven plastic nets are generally made out of high-density polyethylene (HDPE) while polypropylene (PP) is used for non-woven nets. There are three types of weave patterns in nets, namely flat or Italian, English or Leno, and knitted or Raschel (Castellano et al., 2008).

Flat-woven nets are woven in a simple orthogonal pattern, are generally light and stable and do not deform easily. English or Leno woven nets are modified flat nets that contain the same orthogonal pattern, but with a double fiber in the weft direction and provides more durable or rigid protection especially against strong hail storms. Raschel or knitted nets contain longitudinal chains and transversal knitted elements which are linked together to prevent unraveling under strong winds or hail (Castellano et al., 2008). The borders of nets are selveged and contain reinforced buttonholes to enable easy installation and connection to supporting structures. Additives such as chromatic and UV stabilizers, water permeability enhancers or antistatic compounds to reduce dust accumulation are often used and are mixed with HDPE during production (Castellano et al., 2008). For general protection against adverse climatic conditions, white or black nets are used, while for growth manipulation, various colored nets are used (Castellano et al., 2008), however, photoselective nets are more popular in floriculture and vegetables compared to fruit tree production.

Net properties and characteristics. The thickness of the thread determines the thickness of the nets and varies between 0.25 mm and 0.32 mm. Mesh size varies between net types, but for most shade nets it is between 1.7 mm and 7.0 mm, while for anti-hail nets the mesh size varies between 2.5 mm to 4.0 mm. The shading factor describes the nets' ability to absorb a specific percentage of radiation (Castellano et al., 2008), with the most commonly used shade nets absorbing between 12 and 28% photosynthetic active radiation (PAR) (Middleton and McWaters, 2002). Colored nets are termed photoselective nets due to their photoselective and ability to manipulate the radiation spectra (Stamps, 2009). Nets also manipulate the microenvironment by increasing relative humidity (RH) and decreasing air movement which often leads to an increase in soil and air temperatures (Middleton and McWaters, 2002; Murray et al., 2005; Solomakhin and Blanke, 2008; Stamps, 2009).

Adaptation and construction of nets. The first generation of protective nets, developed and used between 1985 and 2004, contained only one transverse fiber which was highly susceptible to wear and tear under excessive weight from rain, hail or snow (Blanke, 2014). First-generation black hail nets also allowed insufficient light through leading to poor fruit color development, especially in areas prone to low light during autumn (Blanke, 2014). The second generation of nets, developed and used extensively between 2005 and 2009, were mostly, but not limited to, photoselective, i.e. colored nets with the selective light transmission in the red spectrum. These did not enhance the coloration of apples as predicted due to less overall light in the tree canopy compared to the small amount of enhanced red light (Blanke, 2014). The third generation of nets, developed and used between 2010 and 2015 consisted of, but not limited to, black and white fibers, which gave nets a grey appearance. These black and white nets compromised light transmission, durability, and longevity (Blanke, 2014). Fourth and future generations began around 2012 which included moveable structures such as retractable roofs (Blanke, 2014).

The mechanics in which the nets are constructed over the orchard may influence the structural and physical properties, and may also be adapted to a specific orchard or growing area. For protection against sun and wind damage, nets are generally fixed as a flat structure to supporting structures made of either wood, metal or concrete or a combination thereof. The flat net structure is cheaper than peaked or pergola structures (Castellano et al., 2008). Anti-hail nets are usually constructed with roof peaks, and the supporting structure requires tensile lower transverse and upper longitudinal steel cables. The net tension is fixed with a slope of 50 to 60% from the longitudinal ridge to allow hail to fall down the middle. Flat structure cables are fixed on the top of the columns and the net spread over and fixed to the longitudinal wire (Castellano et al., 2008). Nets are generally constructed 100cm above the tree tops for most fruit crops, such as citrus (Lee et al., 2005) and apples (Kalcsits et al., 2017).

Environmental conditions under protective nets

Protective nets are used to buffer climatic extremes to maintain a healthier stress-free tree that can remain photosynthetically active for longer periods, and even maintain production during drought years (Girona et al., 2012; Middleton and McWaters, 2002). Environmental conditions vary under nets and are dependent on numerous external factors that are also region-dependent (Kalcsits et al., 2017). In areas such as Germany, reductions in apple tree productivity were observed under three different colored nets that reduced light between 20-23%, due to limited light availability in autumn, compared to Brazil, where no yield reductions were seen (Kalcsits et al., 2017). Excess light in arid regions may also be a limiting factor for optimal tree growth and fruit development (Kalcsits et al., 2017; Taiz et al., 2015d).

Temperature. Protective nets may reduce or increase air temperatures by varying amounts due to 'shading' or 'greenhouse' effects respectively or do not affect the underlying air temperature (Kalcsits et al., 2017; Shahak et al., 2004). Kalcsits et al. (2017) found that temperatures under red nets were lower than those under blue nets, while Tinyane et al. (2018) reported a lower temperature under blue and white nets compared to red nets; however, both trials were in different regions thus showing the role of the external environment. Girona et al. (2012) found that the climate under hail nets that provided 18% shade, installed over a peach orchard in Spain, was slightly warmer and less humid compared to the uncovered control (Girona et al., 2012). Soil temperatures may also affect overall tree performance, especially high soil temperatures that increase root respiration (Kalcsits et al., 2017).

Kalcsits et al. (2017) found that average daily soil temperatures in orchards under the sun almost reached 30 ºC, which may stress apple trees substantially, while under nets mean soil temperatures during the summer months were around 1.5 ºC lower. With the higher soil temperatures in the uncovered controls, soil moisture was found to be lower in the open field compared to soils under various nets (20-23% PAR reduction) (Kalcsits et al., 2017). Ultimately, growers want to reduce the fruit surface temperatures (FST), therefore reducing air temperature and radiation within the orchard by use of shade nets has lead to reductions in FST, and therefore reductions in the physiological disorders such as sunburn (Kalcsits et al., 2017).

Wind speed. Nets act as a barrier thus reducing wind speed and incoming solar radiation into the enclosed or covered area which may reduce external fruit damage (Dussi et al., 2005; Middleton and McWaters, 2002). An increase in shading percentage of nets is positively correlated with an increase in wind speed reduction and a decrease in incoming radiation. Shade percentages are dependent on the type of material, the tread density, thread color and the weave pattern (Blanke, 2014; Castellano et al., 2008; Stamps, 2009). Wind speed was significantly reduced by approximately 40%, with the mean daily wind speed under the net being 2.16 to 2.26 m s^{-1}, compared to uncovered control of 3.27 m s^{-1} in an apple orchard in Washington State, USA (Kalcsits et al., 2017) while Middleton and McWaters (2002) reported a 50% reduction in wind speed in an Australian apple orchard compared to an open block.

Humidity. Relative humidity in the orchard depends on humidity outside the orchard, the wind speed, irrigation and plant density. In Australia, the RH of an open orchard was found to be between 10 to 15% lower than netted areas (Middleton and McWaters, 2002), while in Germany a reduction of 1 to 3% was found (Kalcsits et al., 2017) under similar shading percentage nets of around 20%. Kalcsits et al. (2017) reported RH in the tree canopies under nets to be significantly higher than in trees under full sun, with a negative correlation between daily temperatures and RH percentages.

Light. Light manipulation by the use of photoselective shade nets has resulted in significant improvement in fruit quality (Kalcsits et al., 2017). This has been found for several fruit types such as apples (Dussi et al., 2005; Kalcsits et al., 2017; Solomakhin and Blanke, 2010), peaches (Girona et al., 2012), mandarin (Lee et al., 2015), kiwi (Basile et al., 2012), and plums (Murray et al., 2005).

Irradiance is often higher than the required saturating conditions for leaves, which differ among tree species. Generally, under full sunlight around 2000 µmol m^{-2} s^{-1} PAR is observed compared to, for example, 1260 µmol m^{-2} s^{-1} PAR under white nets and 2000 µmol m^{-2} s^{-1} PAR under green-black nets (Solomakhin and Blanke, 2008), but PAR values are shading percentage dependent.

Some of the most commonly used protective nets reduce the total amount of PAR from, but not limited to, 12 to 30%, while total sunlight may be reduced up to 95% inside the tree canopy itself (Middleton and McWaters, 2002; Solomakhin and Blanke, 2008, 2010). Nets can be designed to specifically meet orchards light requirements, with factors such as type of material used, the weave pattern, the density, the material color, as well as the structure it is set up in, will determine the total quantity and quality of light reaching the trees (Castellano et al., 2008).

A study conducted on the effects of black shade nets on canopy light distribution and fruit quality in apples by Dussi et al. (2005) found that PAR was reduced under both 15 and 55% shade nets, which correlated with a reduction in red-colored fruit, TSS and firmness, and more so in the higher percentage shade net. Leaf measurements also showed that specific leaf weight (SLW) of leaves at lower canopy positions was reduced under nets compared to control fruit (Dussi et al., 2005). Kalcsits et al. (2017) reported a significant reduction in irradiance in trees under pearl nets providing approximately 20% shade, and an increase in light scattering compared to open, uncovered trees. The scattering effect of nets is beneficial to inner parts of the tree canopy (Shahak et al., 2004), which may experience up to 95% sunlight reductions regardless of shade nets (Middleton and McWaters, 2002).

Photoselective (colored) nets may also be used instead of standard white or black nets, but with selectively screening of spectral bands of light, and transforming direct light into scattered light (Basile et al., 2012). Blue nets with a shading percentage of 20.4% reduced shoot growth of kiwifruit vines compared to 22.8 % grey nets that stimulated vigor (Basile et al., 2012) while on apples under 20% green-black nets produced more one-year shoots compared to non-netted trees, and the 14% red-white and 18% red-black shade nets had no effect on vegetative growth (Solomakhin and Blanke, 2010). In Germany, Solomakhin and Blanke (2010) found on a clear sunny day a reduction in light of 12, 14, 18 and 20% in PAR respectively, under white, red-white, red-black, and green-black nets (Solomakhin and Blanke, 2010). The reduced light under the shade nets negatively correlated with increased in tree vigor and lower fruit TSS concentration under the different colored nets (Solomakhin and Blanke, 2010).

Nets and light quality on tree growth and photosynthesis

Vegetative growth. Optimal light distribution in fruit trees requires repeated regulation of vegetative growth. Tree vigor should be in balance with the fruit production of a tree (Basile et al., 2014). Several factors influence the vegetative response in trees under protective nets, such as shade avoidance, increased vigor and apical dominance in one-year shoots (Solomakhin and Blanke, 2008; Basile et al., 2014; Murray et al., 2005). Basile et al. (2014) did a study on kiwi vines under different photoselective nets and found that the percentage of bud break was unaffected, but significant differences in treatments were seen in the distribution of vegetative shoot lengths which were classified respectively, as terminating, intermediate and non-terminating having final lengths of less than 30 cm, between 30 and 100 cm and over 100 cm. Red nets (22.8% shade) produced the lowest number of terminating shoots, and the highest number of intermediate shoots relative to the other net colors such as 20.4% white, 26.9% blue and 27.3% grey nets. The growth of terminating and non-terminating shoots were affected the most. The average internode length of non-terminating shoots was the longest under grey nets, whereas terminating shoots internode length was not affected by the nets. The fresh weight of winter prunings was significantly higher under nets than non-netted controls, with the highest weights recorded from under the red net (Basile et al., 2014). In general, it was found that blue nets reduced vegetative growth, and red and grey nets increased vegetative growth in kiwi vines. The increase in vigor was possibly due to shade responses, improved water status and reduced wind speeds (Basile et al., 2014). The increase in vegetative growth under nets is complex and involves many internal and external orhcard factors that require further study.

Tree canopy and leaf morphology are affected by changes in quantity and quality of light reaching the trees under nets. These changes impact on leaf gas-exchange and photosynthetic patterns, water uptake patterns, and ultimately responses to the different light cues, and are not always consistent (Amarante et al., 2011; Basile et al., 2014; Dussi et al., 2005; Kalcsits et al., 2017; Solomakhin and Blake, 2008). Some of the biggest changes under nets are seen in the vegetative growth patterns. Solomakhin and Blanke (2010) related their findings of reduced starch breakdown on apples to the increased tree vigor under nets which consequently caused more shading reducing starch-sugar convesion. In another study an increase in bourse shoots (vegetative shoots subtend a flower within a mixed bud) and smaller trunk diameters in apple trees due to shade avoidance and photoreceptor responses were reported (Solomakhin and Blanke, 2008, 2010). Limited PAR signals suboptimal light conditions, leading to a cascade of hormone signaling events to increase concentrations of gibberellic acid (GA), which is responsible for shoot elongation. Elongated shoots have a higher chance of capturing PAR than shorter shoots (Rademacher, 2000; Taiz et al., 2015e). However, it is not clear that the increases in vegetative growth under nets are due to limited light alone. Both vegetative and reproductive photomorphogenic responses occur under changing light conditions (Basile et al., 2012), thus an altered spectrum affects the tree as a whole. The literature on increased vegetative growth under nets is limited and varies between plants, as no single response is seen as the result of increased growth and or vigor under nets.

Iglesias and Alegre (2006) reported an increase in apple tree vigor under 25% black shade nets due to improved water use efficiency and photosynthetic capacity, compared to trees under 12% crystal white nets, or not under nets, and found this to be due to reduced environmental stress on the trees under the higher shading percentage nets. The plants' response to shade nets is said to be dependent on the vigor of the plant, where more vigorous plants were found to be more responsive to the nets compared to less vigorous plants (Basile et al., 2014; Middleton and McWaters, 2002).

Plum reproductive buds develop mostly in axillary positions on spurs but can also develop at the nodes of young one-year-old shoots or the axils of leaves (Guerra and Rodrigo, 2015). Maintaining a balance between vegetative and reproductive growth is vital for good return bloom. Middleton and McWaters (2002) reported a reduction in fruit size on vigorous apple trees at three locations, while an increase in fruit size was observed on trees where vigor was controlled. Vegetative growth, or tree vigor, is controlled in several ways, of which chemical growth control will be discussed in a section on PGRs.

Pruning for vigor control also maintains optimal light distribution in the tree canopy. Plums that are situated at lower canopy positions on large trees receive less light due to shading by the upper canopy and are often affected by physiological disorders such as gel breakdown. 'Songold' plums harvested from lower canopy positions are especially affected by gel breakdown (Kruger et al., 2005). Light distribution is also linked to fruit quality characteristics such as color development, TSS and firmness (Kruger et al., 2005). Furthermore, if inappropriate pruning strategies that encourage shoot growth are used on fruit trees under nets, fruit size and yield will also be reduced (Middleton and McWaters, 2002). This may be pruning of bearing positions, over-pruning or pruning at the wrong time.

Photosynthesis. Photosynthesis is the biological process that converts light energy into organic energy which is usable by plants, but it also has limitations under the light. Under light saturating conditions, a process called photoinhibition occurs when too much light is absorbed (Taiz et al., 2015d). An increase in photoinhibition, photorespiration, and photooxidative stress damages or halts the normal functioning of photosynthesis, which may reduce tree productivity (Kalcsits et al., 2017; Taiz et al., 2015d). Several factors influence photosynthesis such as leaf age, position, composition, and numerous external environmental factors, such as the current weather conditions (Štampar et al., 2001). Photosynthesis requires stomatal conductance for gas exchange between the leaf and environment, which is ultimately controlled or influenced by the environment, thus as the name suggests, light is required for the process (Štampar et al., 2001; Taiz et al., 2015a). Irradiance level and temperature are however the two main driving factors of photosynthesis, light having a diurnal effect on the photosynthetic apparatus with a positive correlation between PAR and photosynthetic rates, and temperature which has a negative correlation above 30 ºC for most fruit trees as recorded in Europe (Cosmulescu et al., 2010), whereas Southern Hemisphere trees have adapted to a slightly higher threshold, such as 35 ºC.

Štampar et al. (2001) reported a significant increase in net photosynthesis in 'Elstar' apple trees under 21% black shade nets compared to uncovered trees in full sun, and trees under 6% white shade nets. Solomakhin and Blanke (2008) reported no differences in photosynthesis in apple trees on a sunny day under black or white nets versus trees not under nets, but on a cloudy day, the green-black nets that reduced PAR by 12% decreased leaf photosynthesis by 21% and transpiration by 13% compared to the open control trees. Photosynthesis is only negatively affected under nets when sunlight levels fall below the specific saturation levels of trees, which is found to be around 800 mmol PAR m^{-2} s^{-1} for apples (Solomakhin and Blanke, 2008). The increase in photosynthesis under nets can be explained by the reduction of photoinhibition during light saturating conditions, as well as the increase in light scattering to lower parts of the canopy that might have been previously shaded (Kalcsits et al., 2017; Taiz et al., 2015d). Stomata often close when temperatures and irradiance levels are too high to prevent excess moisture loss or damage to photosystems (Taiz et al., 2015d) due to decrease in vapor pressure deficit (VPD). Therefore, trees under nets are often able to continue with normal photosynthetic processes during unfavorably hot conditions as the VDP is lowered under nets.

Crop load and yield. The source-sink relationship determines where the majority of photosynthates will be spent, and if crop load is very high, photosynthates will be divided among the high number of competing sinks (Basile et al., 2012). In trials done by Basile et al. (2012), various colored nets of different densities were installed over kiwi vines in 2004 resulting in a reduction in crop load the following year whilst return bloom was unaffected. Basile et al. (2012) also saw a reduction in crop load under the blue and grey shade nets (26.9 and 27.3%, respectively) which had higher shade percentages than the white nets (20.4%). The photoselective nets increased the yield of smaller fruit compared to the white nets, which yielded fewer fruit of larger size (Basile et al., 2012).

Crop load and overall yield are affected by both direct (environmental conditions) and indirect (crop load, canopy density, cultivar genetics) factors (Basile et al., 2012). Flowering patterns are influenced by light quantity and quality, and with the increase in light diffusion and or scattering under nets, the potential for improved light absorption to all parts of the canopy is increased (Dussi et al., 2005). Flower induction in 'Pinova' and 'Fuji Kiku' apples may, however, be reduced under nets resulting in a lower return bloom and thus decreased yield (Solomakhin and Blanke, 2008). Yields under nets vary among literature, Amarante et al. (2011) saw a reduction in the number of apple blossoms per cluster on two apple cultivars under white shade nets that reduced PAR by 18.4%, which reduced total yield compared to open trees not under nets, while Štampar et al. (2001) saw an increase in apple yield under 21% black nets compared to 12% white nets and uncovered control trees. Basile et al. (2012) also saw a lower yield in kiwi under nets compared to that of non-netted vines, but fruit weight and size under nets were significantly larger under blue and red nets (Basile et al., 2012). Girona et al. (2012) noted that the combination of water stress and hail nets resulted in lower yields of peach trees, with fruit having a smaller mean size. Return bloom and fruit set under nets were also significantly lower than the uncovered controls (Girona et al., 2012). Štampar et al. (2001) concluded that when combing the effects of both the white and black shade net effects on yield, no significant differences were seen compared to the control, but the effect on fruit quality was significant.

Protective nets effects on external fruit quality

Sunburn / Hail damage. Sunburn is the main reason apples get discarded in some parts of the world that receive high solar radiation (Dussi et al., 2005). Hail damage, on the other hand, will affect areas subjected to spring and/or summer hailstorms, and nets can minimize these losses. Protective nets have become an important tool used to reduce losses in apples, where sunburn losses in the Washington State reached 10% of total fruit, costing the industry around $100 million each year (Mupambi et al., 2018). In South Africa, Tinyane et al. (2017) reported a 40% reduction in marketable yield of avocadoes in an open field compared to fruit from under nets which had a marketable yield of up to 90%. Sunburn may be reduced by decreasing the temperature of the canopies via overhead irrigation, a chemical sun protectant may also be used, or use of shade nets (Dussi et al., 2005).

Shade nets are growing in popularity for use as an addition to sunburn protection, as it protects against wind and hail damage, as well as reducing bird and insect pests. Shade nets which provide even a small percentage of shade have been found to significantly reduce the occurrences of sunburn and wind damage to fruit, as well as improving the packout yield of high-quality class 1 fruit (blemish-free, large, well-shaped and colored) (Brink et al., 2015). 'Granny Smith' apples under shade nets yielded an average 25% reduced sunburn per annum over four years. The decrease in sunburn was reflected in an increase in the percentage of class 1 fruit compared to trees not under nets (Brink et al., 2015).

Kalcsits et al. (2017) assessed the total sunburn of 'Honeycrisp' apples on a modified sunburn severity scale adapted for 'Gala' apples and found that fruit from the uncovered control had a total of 43.5% sunburnt fruit, which was significantly higher than fruit from under shade nets. The pearl-colored net had more sunburnt fruit than from under the blue and red netted trees, with 72, 82 and 80% fruit showing no sunburn symptoms, respectively. Fruit from under the blue and red nets also contained a high proportion of class Y1 (high-grade quality) fruit than fruit from the control. Control fruit had high proportions of fruit marketed as Y2 and Y3 grade (lower grade quality), whilst those with severe sunburn were marked as "tan" and are unmarketable and are discarded by packhouses (Kalcsits et al., 2017). Sunburn damage was also found on citrus fruit, where sun scald from non-netted control trees was significantly higher than under 20% white shade nets, with a total of 8.7% and 3.4%, respectively (Lee et al., 2015).

A typical symptom of sunburn is a light discoloration to the fruit surface in the early stages followed by the onset of cell death creating a strong brown discoloration (Dussi et al., 2015). The cost of setting up a net structure over an orchard is relatively high, but losses due to sunburn can easily exceed any expenses used on nets. Dussi et al. (2005) noted that even mild sunburn damage is not accepted in the export market, thus preventing sunburn will save money in the long run. A study conducted on apples grown in Argentina to determine the efficacy of a 55% and 15% black shade net and compared to non-netted control trees. It was found that sunburn changed the sugar and mineral gradients within the fruit, as well as the ripening characteristics and softening of fruit flesh were increased leading to an increase in rotting of sunburnt fruit during storage (Dussi et al., 2015). Sunburn was reduced up to 99% in the apples grown under the 55% black shade net, and slightly less in apples from trees grown under 15% black shade net, but both reduced sunburn in fruit significantly compared to the uncovered control trees. Both nets reduced the PAR available to the trees, the control received between 65 and 80% PAR, 15% net received between 42 and 51% PAR, and 55% net received between 33 and 37% PAR on the higher canopy positions. The 15% of shaded trees showed no significant differences in the percentage of sunburnt fruit compared to the control; this was possibly due to more fruit under the nets (Dussi et al., 2015). Black nets with a shading percentage of 55% or higher are not considered optimal for color development in deciduous fruit, thus nets with intermediate densities, or lower shading percentages, was recommended (Dussi et al., 2015).

Color development. Anthocyanin production, responsible for the red color in fruit peel, is highly dependent on light (Murray et al., 2005) and temperature, specifically low temperatures which increase anthocyanin production whilst high temperatures decrease production in fruit and plant tissues (Steyn et al., 2005). However, certain cultivars within different fruit types show different responses to both light and temperature regarding anthocyanin production, for example, color development in pears is light-dependent whereas, in apples, most cultivars require low temperatures in addition to light, for red color development (Steyn et al., 2005). Murray et al. (2005) found that the unshaded 'Laetitia' plums at harvest were fully red (20° hue), while fruit from under the 30% shade nets was relatively red (40° hue) and fruit from under the 55% and 80% shade nets had very little red color development. Sun-exposed 'Laetitia' plums were more yellow at harvest, and ground color development was more advanced during ripening compared to shaded fruit. However, during cold storage, the shaded fruit became more yellow compared to non-netted fruit. Hue angle decreased with prolonged cold storage, but the more matured fruit remained redder in cold storage. Air movement under the nets was reduced which lead to lower leaf and fruit temperatures, with the nets providing 70% light having the lowest temperature compared to the control (Murray et al., 2005). Dussi et al. (2005) also found a reduction in red color development in apples under shade nets and noted that at least 70% sunlight is required for optimal red color development in apples (Dussi et al., 2005). Blanke (2009) reported black hail nets were suitable for single-colored green, or bi-colored apple cultivars that are prone to sunburn in Europe, while cultivars that are not susceptible to sunburn and have weaker color development would be better under white or crystal colored hail nets with larger mesh sizes, especially in regions with low sunlight levels.

Protective nets effects on internal fruit quality

Internal disorders. Plums are extremely perishable, therefore low-temperature storage is recommended for maximizing postharvest life. However, long-term cold storage of plums leads to the development of chilling injuries (CI) (Crisosto et al., 2008). Symptoms, such as gel breakdown (GB), internal browning (IB) and internal breakdown develop during fruit ripening after cold storage, which is often only detected once fruit reaches the consumer (Crisosto et al., 2008). The recommended storage temperature for plums is 0 °C to prevent CI (Velardo-Micharet et al., 2017). The alternating or dual temperature regime is used for the export of some plum cultivars from South Africa to maintain uniform ripening, improved flavor, and internal disorder prevention (Velardo-Micharet et al., 2017). This entails fruit stored at -0.5 °C for 8-10 days followed by an increase to 7.5 °C for 5-7 days, then a final reduction back to -0.5 °C for up to 25 days (Louw and Theron, 2012). The regime is often adjusted to suit the cultivar as some cultivars are more susceptible to CI's than others, and due to the presence of less heat shock proteins found in fruit grown under nets (Jooste, 2012), these standard cold storage temperatures might need adjustments as well. Jooste (2012) found intermittent warming reduced CI and delayed the appearance of CI symptoms in Japanese plums compared to those stored at -0.5 °C. Crisosto et al. (2008) found that plum fruit pre-ripened at 20 °C for four days before cold storage softened normally without any physiological disorders, while fruit stored at 5 °C for four weeks followed by four days at 20 °C were soft but lacked juice when squeezed (Crisosto et al., 2008). The lack of juice is due to the formation of gel within the fleshy mesocarp due to modifications in the gelling properties of polyuronides, a polymeric pectic substance consisting of uronic acid (Crisosto et al., 2008). Loss of cell membrane integrity followed by oxidative stress within the fruit is the primary and secondary response to CI (Jooste, 2012). Plum cultivars that are prone to CI, such as 'Sapphire', accumulate high levels of glutathione and polyunsaturated fatty acids during fruit development, which protects it against lipid oxidation while on the tree, but when transferred to cold storage, the high levels of fatty acids are easily oxidized. Cultivars that are CI resistant develop monounsaturated fatty acids instead which are not easily oxidized in long-term cold storage (Jooste, 2012).

High-density orchards with large trees reduce the amount of light intercepted in the lower parts of the canopy, thus maintaining open canopies with an even light distribution is important for optimal photosynthetic capacity (Kruger et al., 2005). Plum fruit from lower shaded positions was found to have a higher incidence of internal disorders than those from sun-exposed positions (Kruger et al., 2005). This was also found for apples (Hamadziripi et al., 2014).

GB in plums is an internal disorder which affects fruit flavor and overall fruit quality, develops during cold storage, and is greatly influenced by harvest maturity. GB manifests between the stone and middle of the mesocarp in more mature fruit during storage, yet too early harvests will result in fruit not ripening optimally (Taylor et al., 1995). GB in plums is similar to mealiness in peaches, where high molecular weight pectin binds to water molecules which then leak into the cell wall area during ripening, forming a gel-like structure (Taylor et al., 1995). Taylor et al. (1995) found that the TSS concentration of optimally mature 'Songold' plums harvested at a firmness of 64 N, was significantly lower than in post-optimum mature plums harvested at a firmness of 44 N, two weeks later. The TSS of post-optimum maturity fruit remained lower throughout the cold storage period, indicating the importance of the optimal harvest period (Taylor, et al., 1995). It was also found that the occurrence of GB was significantly higher in the post-optimum mature fruit compared to optimum mature fruit by as much as 21.6% after cold storage (Taylor et al., 1995). Similarly, fruit maturity levels at harvest from shaded fruit were consistently lower than sun-exposed fruit (Murray et al., 2005).

IB in plums is another internal disorder similar to GB but occurs around the outer regions of mesocarp, often observed as a brown area covering the fruit below the peel. Internal browning reduces the plum's ability to ripen which reduces consumer acceptance (Crisosto et al., 2008). Jooste (2012) found a significant interaction between harvest maturity, cold storage duration, and temperature for cases of IB in Japanese plums. IB only started to manifest after 3 weeks of cold storage in plums harvested after the optimal date, and in plums that were harvested first on the commercial harvest date, IB occurred a week later when stored at 10 °C, further IB levels increased with an increase in storage duration at -0.5 °C (Jooste, 2012).

Flesh firmness, TSS and TA. Dussi et al. (2005) found that shading reduced the TSS concentration of apples, while firmness was unaffected under 15% shade nets, but lower firmness was recorded in apples under the 55% shade nets (Dussi et al., 2005). Girona et al (2012) found that peaches from netted trees had a lower TSS concentration than fruit from sun-exposed trees, whereas fruit firmness was similar for both treatments (Girona et al., 2012).

Internal quality parameters differ in fruit grown under nets, but the environment of the specific growing season may have a larger impact than the nets alone. Murray et al. (2005) found that at harvest, 'Laetitia' plums from under shade nets were smaller, firmer, and the TSS was lower than fruit grown in full sun, while in 'Songold' plums the TSS was lower under shade nets that allowed through 45 and 25% sunlight (Murray et al., 2005). Shaded 'Songold' plums were firmer, however, shaded fruit firmness decreased more rapidly after storage than in sun-exposed fruit. The smaller fruit size of the shaded treatments was likely due to reduced carbohydrate levels, as light-saturated net CO2 assimilation rates and nitrogen concentrations in shaded leaves were significantly lower than in sun-exposed leaves (Murray et al., 2005). During postharvest storage, flesh firmness, TSS and TA decreased, while peel color development increased. Internal disorders may be initiated preharvest due to shading, but develop during cold storage (Murray et al., 2005). Jooste (2012) found a significant correlation between harvest maturity, storage duration, and temperature, on plum flesh firmness, which also linked to CI levels, and reported that 'Sapphire' plums should be harvested while they less mature and not be stored for extended periods to maintain a suitable firmness and prevent CI (Jooste, 2012), this might be useful to apply to plums grown under nets as maturity differences are often seen.

Pollination and fruit set under nets

Flowering and Pollination. Japanese plum cultivars are all diploid (2n) and are self-incompatible, therefore they require cross-pollination from a compatible cultivar, as fruit does not set parthenocarpically (Hartmann and Nuemüller, 2009). Japanese plums flower early in the season, and have much higher flower set percentages than European plums (Hartmann and Nuemüllller, 2009). In self-pollination experiments on Japanese plums, none of the cultivars showed any fruit set (Guerra et al., 2010). Low fruit set in various cultivars may be due to reproductive failures, lack of pollination, ovule degeneration, and self-incompatibility (Guerra et al., 2010; Guerra and Rodrigo, 2015). Plum flower buds develop in leaf axils during the summer and autumn before the spring in which the flowers open on both one-year shoots and spurs. Flower initiation depends on the cultivar, and the physiological condition of the tree which is affected by weather, and various orchard factors and cultural practices (Guerra and Rodrigo, 2015). Light scattering is increased under nets thus improving light penetration into the tree canopy (Basile et al., 2012; Kalcsits et al., 2017). More light into all parts of the tree canopy improves flower distribution.

Flower bud development enters dormancy after leaf drop, and a cultivar-specific amount of chilling during dormancy is required during winter months to allow normal bud break in late winter/early spring (Guerra and Rodrigo, 2015). Once the chilling requirement is fulfilled, a certain amount of warm weather is required for bud break and bloom. Japanese plums flower early in the season, with a very short bloom period. The most effective pollination period is one to three days after the opening of the flower (Guerra and Rodrigo, 2015). Temperature affects the rate of pollen tube growth, with lower temperatures decreasing the rate, which affects pollen viability and thus successful fertilization and final fruit set. An optimum temperate between 22 and 25 °C was found for prunes grown in California (DeCeault and Polito, 2010; Guerra and Rodrigo, 2015). Air temperatures under nets may, therefore, affect flowering by either positively by allowing a longer pollination period due to decrease in temperature fluctuations (DeCeault and Polito, 2010; Guerra and Rodrigo, 2015), or negatively by affecting return bloom due to increased vegetative growth (Solomakhin and Blanke, 2008).

Return bloom and fruit set. A common competitive factor under shade nets is increased vegetative growth before flower bud initiation which utilizes carbohydrate reserves. Vigorous vegetative growth under netting structures can be managed by the application of plant growth regulators (Zhang and Whiting, 2013; Dussi et al., 2005). Some studies have shown that red and white-colored shade nets had better fruit set when compared to other colors, while other studies show no significant fruit set differences under different net colors, but only under different net densities, with increasing density worsening fruit set (Dussi et al., 2005).

Flower bud strength may be reduced under nets due to lower light levels, which can lead to lower fruit set (Solomakhin and Blanke, 2008; Taiz et al., 2015b). The decrease in light levels favors vegetative bud development to increase the photosynthetic capacity of the tree (Taiz et al., 2015a). The remaining fruit that does set under nets tend to grow more strongly and are of better quality due to less competition (Basile et al., 2012; Dussi et al., 2005). Fruit set, just like any other metabolic process, requires sufficient energy resources, and any type of competition may result in decreased set. Girona et al. (2012) found that the return bloom of peach trees under nets was lower than trees not under nets, and thus fruit set was reduced (Girona et al., 2012).

In two apple cultivars 'Gala' and 'Fuji', the number of blossom clusters per cm2 of limb cross-sectional area was significantly reduced under 18.4% white nets, while in peach cultivars the number of flower clusters under 30% blue, red and pearl, and 18% red-white and 12% white nets was significantly increased compared to uncovered controls (Amarante et al., 2011). The different response was said to be species and net color-dependent. Fruit set was unaffected in 'Fuji' apples under various colored nets, but in 'Hi Early' apples under black nets, it was consistently reduced over four seasons compared to uncovered controls. Flower bud development and return bloom was found to be slightly negatively affected by nets due to the decrease in incident light, leading to greater competition for resources between vegetative and reproductive growth (Amarante et al., 2011). Also, a reduction in reserves over time was found to decrease return bloom (Girona et al., 2012).

Bee activity. Any type of covering over crops changes the temperature, irradiance and light quality, humidity and wind speed of the environment beneath (Goodwin, 2012; Kalcsits et al., 2017; Middleton and McWaters, 2002). Protective nets affect normal bee activity as would occur in an orchard not covered by nets, and bees are generally less inclined to fly under nets (Goodwin, 2012; Middleton and McWaters, 2002). Bumblebees and honeybees are most widely used for pollination, with honeybees being used in South Africa. Honeybees can easily become tangled in certain net types or trapped causing them to die from stress. Netting should be installed in such a way that bees can move freely between rows, and in and out of hives without having to fly out too far of the netted area, as they may not be able to get back in (Goodwin, 2012; Middleton and McWaters, 2002). Bees thrive on a variety of food, thus removing all cover crops before bringing in the hives may harm bee activity (Goodwin, 2012). Bees should be introduced into the netted area at 3 to 5% bloom, and if possible, temporary removal of nets during full bloom is highly beneficial to bee productivity (Middleton and McWaters, 2002).

Chemicals used for plant protection and growth manipulation under nets have different evaporation and drying characteristics which can directly affect bee activity (Goodwin, 2012). An increase in humidity under nets often leads to an increase in fungicide use. High humidity also dilutes the nectar of flowers making them less attractive to bees. Air temperature is usually lower under nets which are favorable to bees on hot days, but detrimental on cold days as warming of the hives takes longer. The amount of ultraviolet light is reduced under nets, which greatly confuses the vision of bees (Goodwin, 2012). Trees should be well pruned before bees are brought into the orchard to allow them to fly freely between rows. The same hive colonies should be used each season as bees become accustomed to the netting structure. Hives that are moved between netted and open orchards confuse bees, as the bees try to fly the same distance and direction as before, often resulting in them flying against the roof or becoming bunched in corners until they die. Despite the number of bees that get lost, disorientated or trapped in the net structure, most bees become accustomed to the nets and find their way around (Goodwin, 2012; Middleton and McWaters, 2002).

Plant Growth Regulators

Efficient tree management is an important aspect of fruit production, and the balance between vegetative and reproductive growth can be maintained by the use of PGRs (Rademacher, 2004). Reducing excessive shoot growth in young trees will induce earlier flowering and fruiting, while in older trees crowding and shading are reduced (Rademacher, 2004). Maintaining an open canopy in trees also improves light penetration and therefore photo assimilation, fruit color development, as well as facilitating better crop protection strategies (Rademacher, 2004). Pruning alone for tree size control is also an expensive and time-consuming process, and may affect flowering and yield (Lurie et al., 1997).

Plant growth retardants are synthetic compounds that reduce the vegetative growth of plants without negatively affecting developmental patterns, yield or being phytotoxic (Rademacher, 2000). Plant growth retardants act by reducing cell elongation as well as lowering the rate of cell division by antagonizing growth-promoting hormones such as auxin (IAA) and gibberellin (GA) (Rademacher, 2000). The effectiveness of PGRs is determined by the ease with which is it taken up by the plant and transported to the necessary action sites, and the efficiency by which it interferes with endogenous control systems that regulate plant growth (Quinlan and Richardson, 1986).

The first use of PGRs were nicotinuim derivatives and came as early as 1949. Many other compounds have since been detected and are used commercially as growth regulators, herbicides, insecticides and fungicides, all classified as bioregulators (Rademacher, 2000). Bioregulators can be used flexibly by farmers who wish to attain a certain level of growth control, as long as the given restrictions are followed (Rademacher, 2000). Growth retardants can be classified into two groups, those that release ethylene, and those that inhibit GA biosynthesis; only the latter group will be discussed further.

Gibberellins are important plant hormones that promote growth extension, seed germination, bolting of long-day plants, as well as fruit set and development (Rademacher, 2000; Taiz et al., 2015e), and are synthesized in developing and germinating seeds, developing leaves and elongating internodes (Taiz et al., 2015e). Gibberellin biosynthesis is separated into three stages according to the enzymes involved and location of the reactions in the cell: Terpene cyclase's which act in proplastids, monooxygenases which are associated with the endoplasmic reticulum and dioxygenases which are found in the cytosol (Rademacher, 2000). By inhibiting GA biosynthesis, shoot growth extension is retarded (Quinlan and Richardson, 1986).

There are four known groups of GA biosynthesis inhibitors (Rademacher, 2000):

1) Onium-type compounds possess a positively charged ammonium, phosphonium or sulphonium group that blocks GA biosynthesis directly before the formation of ent-kaurene. The most common are chlormequat chloride and mepiquat chloride compounds. These compounds have a quaternary ammonium group and are used as anti-lodging agents in cereals and growth regulation in cotton. Chlormequat chloride was used on fruit trees to control vegetative growth; however, commercial use of the product is no longer allowed on fruit trees (Aśin and Vilardell, 2006).

2) Compounds containing a nitrogen heterocycle, which inhibit monooxygenases catalyzing the oxidative steps from ent-kaureno to ent-kaurenoic acid. Common compounds include pyrimidines, such as ancymidol and flurprimidol which are used in ornamentals, and certain triazoles such as PBZ and the closely related UCZ which are actively used in fruit trees, ornamentals, and rice. The common structural feature of these compounds is a one-electron pair on the sp2-hybridized nitrogen of their heterocyclic ring. The lone pair of electrons displaces oxygen from its binding site at the protoheme iron of the targeted monooxygenase. These PGRs types also affect various hormones other than GAs, such as increasing levels of cytokinin's, decrease ethylene levels, and increase in abscisic acid (Rademacher, 2000). These effects seem to be non-specific, as plants under the influence of heterocyclic PGRs tend to shift assimilates towards the roots, stimulating root growth which in turn stimulates cytokinin production. Triazole-type compounds have shown to block

aminocyclopropane carboxylic acid (ACC) oxidase, thereby reducing ethylene formation, also an indirect effect as ACC oxidase is a dioxygenase-type enzyme, which is a target for triazoles.

3) Compounds that structurally mimic 2-oxoglutaric acid, such as the group of acylcyclohexanediones, which block the final reactions of GA metabolism. Compounds such as Pro-Ca and trinexapac-ethyl are commonly used acylcyclohexanediones. Structural similarities exist between the acylcyclohexanediones and 2-oxoglutaric acid, which is the dioxygenase co-substrate required for GA metabolism. Growth reduction is caused by lowering levels of biologically active GA1 and its metabolite GA8, as well as increasing concentrations of non-active GA20. Growth retardation via acylcyclohexanediones can be reversed by active GAs produced in the early stages of GA biosynthesis. In some cases, these compounds lead to increased shoot growth, due to endogenous active GAs not being metabolically inactivated by the acylclohexanediones. Acylcyclohexanediones have also shown to affect different enzymes in GA biosynthesis, reducing ethylene levels in sunflower cell suspensions, as well as increasing levels of cytokinins and abscisic acid in shoots of wheat and oilseed rape.

4) 16,17-Dihydro-GAs are the most recent group of GA biosynthesis inhibitors and are mostly GA5 derivatives, and reduce shoot growth in various grasses. Evidence suggests their growth retarding activity is due to inhibition of dioxygenases catalyzing the late stages of GA metabolism, similar to acylclohexanediones. The biological activity of GA1 is also stimulated by compounds of GA derivatives.

Paclobutrazol. Paclobutrazol is a commonly used triazole-type compound with a nitrogen-containing heterocycle. Paclobutrazol is applied either as a foliar spray, soil drench or via root injection. Translocation of PBZ, when applied to the roots or foliage, is through the xylem after being absorbed by the roots or stem and shoot tissues, respectively. Apart from retarding shoot extension growth, PBZ also intensifies the green color and thickness of leaves and increasing spur development and flowering, but several leaves and leaf size may be reduced (Edgerton, 1986). Problems regarding PBZ are that it is only registered in some countries creating an export barrier, it is extremely persistent, and moves in a strict acropetal direction (Lurie et al., 1997; Rademacher, 2004). Residues above maximum levels are often found in fruit as well as flattened fruit shapes become evident in treated trees (Rademacher, 2004).

Paclobutrazol is the main active ingredient in Cultar® (Syngenta Crop Protection AG, Switzerland), and has received a lot of attention since 1980 as a powerful growth regulator for fruit trees such as apple, peach, apricot, pear, cherry, and plum (Shearing and Jones, 1986). Results such as reducing pruning requirements, greater flower bud induction, yield, and improved quality were found (Lurie et al., 1997; Shearing and Jones, 1986). Olivier et al. (1990) found that autumn applications of PBZ (250 and 500 mg dm^{-3}) to 'Songold' plum trees significantly increased earlier flower bud break, as well the dry weight and size of flowers. Dry matter allocation to reproductive growth was also favored before shoot growth commenced (Olivier et al., 1990). Since the changes in floral buds occur before shoot growth commences, the effect of PBZ on potentially increasing fruit size may be due to both the inhibition of shoot growth and earlier floral bud development (Olivier et al., 1990).

Shearing and Jones (1986) found a successful reduction in vegetative growth in 'Red Haven' peach trees treated with PBZ in Italy. Soil applications applied as a band spray around the trunk in spring successfully controlled vegetative growth, with up to 31% growth retardation compared to untreated control. Improved yield and fruit size of the peaches at both 0.5 and 1.0 $kg{\cdot}ha^{-1}$ occurred (Shearing and Jones, 1986). There was no significant difference between the concentrations, only between treatment and control. The timing of the applications was a pre-bud break during spring rain and summer irrigation to ensure sufficient root uptake (Shearing and Jones, 1986). Timing is important, especially in non-irrigated orchards. In a second trial conducted in South Carolina, USA, on 'Loring' peach trees in a non-irrigated orchard, Shearing and Jones (1986) found that spring applications in May did not successfully control vegetative growth compared to winter applications in December. Two applications of the same concentrations of 0.28 and 0.56 kg ha^{-1} of PBZ were made in December and May. Growth reductions in December were up to 33% while the spring only application only reduced growth by 16 to 19%. No significant differences were found between the different concentrations, only timing (Shearing and Jones, 1986).

Edgerton (1986) found PBZ (soil and foliar application) effective in reducing the growth of apple, peach and cherry trees (Edgerton, 1286). Paclobutrazol was applied either by injecting the chemical below the soil surface or by direct applications around the trunk in spring. On 'Idared' apples, two soil drenches per tree were done using 0.2 $g{\cdot}L^{-1}$ PBZ and broadcast over a 2.3 m^2 area around the trunk. Older apple trees with trunk circumferences greater than 15 cm showed little to no response the first season, and unpredictable responses the second season, particularly on older vigorous trees (Edgerton, 1986). Foliar applications of PBZ starting with a pre-bloom spray, followed by two or three post-bloom sprays totaling a final concentration of 500 to 1000 $g{\cdot}L^{-1}$ were effective in controlling vegetative growth of 'Idared' apple trees, as well as enhancing flowering and total yield. A total of 40 to 60% growth control was achieved compared to untreated controls (Edgerton, 1986).

Quinlan and Richardson (1986) also found that two or more applications of PBZ on 'Idared' apples gave better results in controlling vegetative growth, rather than one application of equal concentrations (Quinlan and Richardson, 1986). It was found that a single foliar application of 2000 $g \cdot L^{-1}$ on apple trees three weeks after full bloom decreased mean shoot growth by 25%, whilst four sequential sprays of 500 $g \cdot L^{-1}$, three, five, seven and nine weeks after full bloom decreased mean shoot growth by 62%, compared to an untreated control (Quinlan and Richardson, 1986). Paclobutrazol is more effective when applied directly to or translocated to the apical region of the shoot in retarding shoot extension, than when the chemical is localized in other parts of the shoot (Quinlan and Richardson, 1986). In apples, foliar uptake occurs via the young green shoots, with little uptake occurring through woody shoots (Shearing and Jones, 1986). This explained why the sequential application of sprays gave better results than one single application (Quinlan and Richardson, 1986), which is confirmed by Shearing and Jones (1986), stating that pre-bloom applications, followed by another application two weeks after bloom, can increase early growth retardation (Shearing and Jones, 1986).

Uniconazole. Uniconazole is another triazole-type compound with a nitrogen-containing heterocycle and a close relative of PBZ. Uniconazole (Tradename MagicTM, Shimatzu) was evaluated as a vegetative growth retardant on various fruit trees such as mangos, apples, olives, avocados (Silva et al., 2010), yet little research has been conducted on its effectiveness on plum trees. Silva et al. (2010) evaluated three concentrations of foliar-applied UCZ, at 500, 1000 and 1500 $mg \cdot L^{-1}$, combined with one soil application of PCZ at 2.0 $g \cdot m^{-1}$ tree canopy, applied at the end of the second vegetative flush on mango trees in Brazil. After 30 days, no significant results were obtained with a single application of all three concentrations of UCZ, whereas a significant reduction in branching was found with applications of soil-applied PBZ after 60 and 90 days (Silva et al., 2010). Inhibition of branch development was found after two applications of UCZ as foliar sprays and one soil application of PBZ. This inhibition was proportional to the dosage, with fewer vegetative buds developing at higher doses. The efficacy of the product was temperature-dependent, with higher temperatures reducing the efficacy of UCZ (Silva et al., 2010). All three treatments significantly reduced vegetative growth compared to the controls, with 1500 $mg \cdot L^{-1}$ UCZ being the most significant, similar to PBZ. Therefore, Silva et al. (2010) concluded that two or more foliar applications of UCZ showed inhibition of vegetative growth on mangoes (Silva et al., 2010).

Schneider et al. (2010) investigated the effectiveness of soil and foliar applied UCZ in reducing vegetative growth in olive trees. The effectiveness of soil-applied UCZ, as in the case for PBZ, is influenced by the amount of soil organic matter, as these triazoles are easily absorbed by soil organic matter. High water levels in the soil also reduced the absorption of UCZ by the roots, and since the half-life of UCZ is three to four months, a foliar application was favored (Schneider et al., 2010). Soil applications at the beginning of florescence elongation at 1.0 or 2.0 ml·L^{-1} in using the commercial UCZ product MagicTM (Sumitomo Chemicals, Hyogo-Ken, Japan) showed no significant effects on tree growth. However, four foliar spray treatments of 0.75 or 1.5 g·L^{-1} showed significant shoot growth inhibition (Schneider et al., 2010).

Lurie et al. (1997) investigated the effects of a spring application after flowering of PBZ (Cultarâ, ICI) and UCZ (MagicTM, Shimatzu) on 'Red Rosa' Japanese plum fruit development and storage quality over two seasons Fruit were harvested from a different tree three times during both seasons when most of the fruit were uniform in size and color. During the first season, fruit weight was increased significantly by both PBZ and UCZ, using 500 and 1000 mg·L^{-1} per tree and 100 and 200 mg·L^{-1} per tree, respectively, whilst no significant difference was found in total yield. However, a greater percentage of large fruit with a diameter above 50 mm was found following both chemical treatments. Bud break occurred 10 days earlier on treated trees compared to untreated controls and thus flowering occurred earlier the following season, allowing for a longer growing period for the fruit to increase in size, similar to what Olivier et al. (1990) found on 'Songold' plums. Of the total number of trees treated with either PBZ or UCZ, at least 69% were in full bloom compared to only 14% of the untreated control trees when analyzed on the same date (Lurie et al., 1997). Peel color developed more rapidly to a darker red color (lower hue values) in both PBZ and UCZ treated trees at the first harvest compared to the untreated control, whilst at the commercial harvest some weeks later all fruit were similar in color. Fruit from PBZ treatments had the same firmness and TSS concentration as control fruit. Differences between postharvest characteristics, such as firmness, TSS, and TA were greater between the three harvest periods and seasons than between treatments. After four weeks of cold storage at 0 °C, no internal disorders were found in either treatment, only after six weeks, physiological disorders became prominent. Fruit from all treatments harvested during the last period developed some internal browning and gel breakdown after a shelf life period. They concluded that PBZ and UCZ significantly increased fruit weight, size, and red color development, but did not affect firmness, TSS, TA or storage quality. Since plum fruit is harvested according to red color development, earlier color development might lead to earlier harvesting, and could negatively influence taste as the TA: TSS ratio is higher than when fruits are harvested later (Lurie et al., 1997).

Prohexadione calcium. Prohexadione calcium was developed in the 1990s as a growth retardant to control excessive vegetative growth in pome and stone fruit by inhibiting the biosynthesis of the biologically active gibberellins A1, A4 and A7 (Rademacher et al., 2006; Ramírez et al., 2010).

Prohexadione calcium offers an improved solution to vegetative growth control and has been introduced to many countries since 2000 (Rademacher et al., 2006), under the trade names Apogee® (BASF, USA) and Regalis® (BASF, Europe). Prohexadione calcium primarily inhibits deoxygenases that catalyze specific steps in GA biosynthesis and as a side activity, the formation of ethylene and flavonoids are blocked (Rademacher, 2004). By lowering the active GA content, vegetative growth is reduced, and fruit set may be increased (Costa et al., 2006). The compound is relatively short-lived, shows favorable toxicological and ecotoxicological characteristics, and very low if any, residues are picked up in fruits (Costa et al., 2006; Rademacher et al., 2006). The compound is applied to growing shoots and translocated acropetally. Pruning costs are reduced by up to 30%, higher yields are obtained, improved fruit quality and fruit storage quality is obtained, as well as tolerance to various pathogens such as fire blight (Rademacher, 2004). A reduction in young fruit drop in pome trees has also been found in ProCa treated trees due to the reduced ethylene formation (Rademacher et al., 2006). Due to its acropetal transport in the xylem, directed sprays can be applied to control shoot growth in distinct parts of the tree (Rademacher et al., 2006).

Studies also show that ProCa may participate in secondary metabolite pathways linked to antioxidant status in the fruit, as well as influence and or modify the enzymatic system activities (Ramírez et al., 2010). Ramírez et al. (2010) found a total increase in antioxidant levels in ripe 'Golden Delicious' apples when ProCa was applied to the trees via a backpack sprayer in early spring when shoot growth was 5 cm in length at concentrations 125, 175 and 250 $mg \cdot L^{-1}$, in addition to the significant reduction in shoot growth. The highest concentration resulted in the greatest reduction of shoot growth, although no significant differences existed between the different concentrations. Increased antioxidant content leads to an increase in storage quality, as the production of free radicals decreased during the normal catabolic respiratory climacteric (Ramírez et al., 2010).

Aśin and Vilardell (2006) found that the use of chlormequat chloride (CCC) was most effective in controlling vegetative growth compared to Cultar® (Syngenta Crop Protection AG, Switzerland) and Regalis® (BASF, Europe) on the pear cultivar 'Blanquilla' at 500, 250 and 175 $g \cdot L^{-1}$, respectively. CCC was sprayed via three foliar sprays, Cultar® as a single spray and Regalis® as four sprays. Results show that the highest percentage of shoots less than 40 cm in length were that of CCC treatments with a total of 69%, followed by Cultar® and Regalis® with 62 and 56%, respectively. There was no significant difference between Regalis® and Cultar® on the 5% significance level, the same was found for their average shoot length after treatment (Aśin and Vilardell, 2006). In the second trial done on the pear cultivar 'Conference', no significant differences in vegetative growth were seen as shoot growth occurred over two periods and their treatment spray schedule was found to be inappropriate with the growth flushes, or too low doses of Cultar® were used. A final remark made from their results was to obtain results similar to that of CCC, which is now banned on apples and pears, Cultar® and Regalis® should be used together. It would then be possible to have the lowest shoot growth rate from a single Cultar® application combined with a rapid response rate associated with Regalis® applications (Aśin and Vilardell, 2006).

Conclusion

Production of high-quality plum fruit is an important factor ensuring an economic return to both the grower and exporting country (Erogul and Sen, 2015; Moser et al., 2011). Preharvest orchard management practices are important to maintain consistent production, and harsh environmental factors may disrupt a high yield causing up to 80% damage to fruit, resulting in low grade and even unmarketable fruit (Basile et al., 2014; Brink et al., 2015; Kalcsits et al., 2017). The use of protective nets results in an overall reduction in physical damage to various fruit types, mainly reduced hail, wind and sunburn damage (Basile et al., 2014; Kalcsits et al., 2017; Murray et al., 2005). In areas that experience radiation-related damages, permanent flat structures using white or black shade nets are most commonly used, while areas that are prone to hail or snowfall have more gabled or retractable structures (Castellano et al., 2008). Light is important for fruit development, influencing factors such as color development, size, harvest maturity, and yield. A general reduction in TSS content was found for most fruit types grown under protective nets (Dussi et al., 2005; Girona et al., 2012; Murray et al., 2005), while fleshing firmness results varied (Murray et al., 2005). Red color development was also found to be less on netted fruit compared to uncovered controls (Dussi et al., 2005), and fruit were generally less mature at harvest (Basile et al., 2012; Murray et al., 2005; Usenik et al., 2008; Velardo-Micharet et al., 2017). Vegetative growth under nets tended to be more vigorous than non-netted trees and vines (Basile et al., 2014; Middleton and McWaters, 2002). Return bloom and fruit set were slightly reduced under nets compared to non-netted trees (Amarante et al., 2011; Dussi et al., 2005; Girona et al., 2012). Vegetative and reproductive growth should be maintained by pruning and thinning trees throughout the seasons, while the use of PGRs reduce thinning and pruning costs up to 30% (Rademacher, 2004). Due to the hazardous properties of many previously used PGRs, new chemicals have been tested and proven to be effective growth retardants on fruit trees, while showing good ecotoxicological and toxicological properties (Aśin and Vilardell, 2006; Rademacher 2004; Ramirez et al., 2010). Significant results have been observed with the use of PBZ and UCZ, as soil or foliar treatment at various concentrations compared to untreated controls, and even more promising is Pro-Ca which was found to be effective at both low and high concentrations (Rademacher 2004; Ramírez et al., 2010). By looking at the numerous studies, the overall effect of protective nets compared to uncovered controls outweighs the small number of negative effects.

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PAPER 1: Impact of Shade Nets on Japanese Plum (*Prunus salicina* Lindl.) Yield and Fruit Quality

Abstract. **Protective nets are gaining in popularity amongst fruit growers across the world as a means to improve fruit quality without compromising yield. The effects of a 20% crystal white shade net, installed as a permanent flat structure over a Japanese plum orchard in the Western Cape Province, South Africa, on the yield and fruit quality of 'Larry Ann' and 'Midnight Gold' were investigated over two growing seasons. Fruit were harvested at physiologically maturity. Fruit were subjected to maturity indexing at harvest, and after being stored at -0.5 °C for 6 weeks, and after 1 week at 10 °C to simulate shelf-life. The nets reduced daily air temperatures by ca. 1 °C on average, while soil temperatures increased by ca. 1 °C on average. Bee activity was found to be directly related to daily temperatures where cold days resulted in little to no bee activity, both under the nets and in the open air. Relative humidity under the nets differed no more than ca. 5% throughout the season, with late summer months having higher RH under nets. Light and wind were reduced, resulting in a reduction in sunburn and scuff marks in both cultivars. The shade nets resulted in a decrease in yield efficiency, and fruit size of 'Larry Ann' in the 2016/2017 season, while yield, yield efficiency and fruit size decreased in 'Midnight Gold' in the 2017/2018 season. Both cultivars from under the nets were less firm than the controls at harvest, and although significant differences were often found in total soluble solid concentrations and total acidity percentage, these were horticulturally insignificant. Nets generally increased the lightness in 'Larry Ann' and to a lesser extent decreased it in 'Midnight Gold', while hue angle was mostly unaffected, and chroma generally decreased in both cultivars. After six weeks of cold storage both cultivars harvested from under the nets generally had fewer internal disorders than the controls, albeit very low percentages were recorded, however, after one-week shelf-life a greater percentage of decay and aerated tissue was found 'Midnight Gold', and to a lesser extend internal browning, and gel breakdown in 'Larry Ann' harvested from under the nets.**

Additional index words. 'Midnight Gold', 'Larry Ann', fruit color, cold storage, Western Cape, orchard microclimate, protective net

The South African Japanese plum industry is the second-largest exporter of fresh plums world-wide, with most fruit going to Europe. It is the third-largest producer of fresh plums in the southern hemisphere (Hortgro, 2017), thus producing high-quality fruit is important to remain competitive. Many growers have, however, experienced a reduction in Class 1 fruit in recent years, due to more discerning markets, as well as heat damage and sunburn in orchards (Personal communication, Petru Du Plessis). Damaged fruit are either downgraded or discarded, lowering economic returns (Dussi et al., 2005; Murray et al., 2005). Long term climate predictions for South Africa are that summers will become warmer with more severe heatwaves, and thus the damage is expected to worsen in the future (Midgley et al., 2016).

The main purpose of covering crops with nets is to protect it from meteorological hazards, insects, birds, and small animals (Castellano et al., 2008), and are used extensively in the cut flower, vegetable, nursery and fruit production industries (Dussi et al., 2005). With the increase in hailstorms and heatwaves across the globe (Midgely et al., 2016), nets serve as a sustainable long-term choice of protection to trees and fruit quality (Solomakhin and Blanke, 2010), and many growers have already responded by covering their crop with nets as protection. Unfortunately, a decrease in return bloom, fruit set, fruit coloration as well as an increase in tree vigor have been observed in numerous covered crops thus affecting yield and fruit quality (Basile et al., 2012; Dussi et al., 2005; Kalcsits et al., 2017; Middleton and McWaters, 2000; Murray et al., 2005; Solomakhin and Blanke, 2010). To our knowledge, little research has been done on the effect of shade nets on yield and fruit quality of Japanese plums, and even less under South African conditions.

Classification of nets is based on the type and color of the material, the thread density and weave pattern, the shading factor, porosity, durability and its mechanical characteristics (Castellano et al., 2008). This makes the comparison of results from numerous trials both under nets and not under nets slightly challenging for plums as research is limited, however Mupambi et al. (2018) have done this with apples. Nets reduce or alter incoming photosynthetically active radiation (PAR; 400-700 nm), affecting both tree growth and fruit development to varying degrees (Blanke, 2009; Dussi et al., 2005). Most commonly used nets are white or black in color and block between 12 and 30% incoming light (Blanke, 2009; Middleton and McWaters, 2000). Murray et al. (2005) found that ‘Laetitia’ and ‘Songold’ plums required at least 70% sunlight during the orchard phase for optimal color development during post-harvest cold storage, particularly red color development. Various colored nets (photoselective nets) are also gaining popularity, yet their effects on crop physiology are inconsistent (Mupambi et al., 2018), a few examples of such, but not limited to the following, have indicated that blue nets reduce shoot growth in kiwi fruit vines and cause dwarfism in ornamentals, compared to grey nets which stimulate vine vigor and growth of short branches with small leaves in kiwis (Basile et al., 2012; Castellano et al., 2008). For general protection against adverse weather conditions, white or black nets are often used.

High fruit quality remains the most important factor to gain access to high-end markets, ensuring a good economic return (Basile et al., 2012). The fruit quality is established on the tree and is directly influenced by the orchard environment (Solomakhin and Blanke, 2010) and management practices (Amarante et al., 2011). Since the cost of protective net installation is relatively high, orchard productivity needs to be optimal to ensure a good yield of high-quality fruit (Middleton and McWaters, 2000). Middleton and McWaters (2002) found in numerous apple cultivars that fruit size was reduced under nets especially on vigorous trees, or similar or larger on dwarfing to semi-dwarfing trees. A reduction in crop load under nets due to lower fruit set would theoretically imply that remaining fruit would become stronger sinks, however, the increase in vegetative growth under nets, as was found by Middleton and McWaters (2002) where both the number and length of shoots increases, reduced fruit size. The reduced fruit set under nets can, however, reduce fruit thinning requirements and potentially reduce management costs (Middleton and McWaters, 2002)

Internal fruit quality is related to harvest maturity, and generally, fruit harvested from under protective nets tend to mature slower than fruit in full sun (Amarante et al., 2011; Basile et al., 2012). For plums, physical parameters such as fruit firmness, mass, appearance, and the total soluble solids (TSS) concentration to total titratable acidity (TA) ratios are used to determine when to harvest fruit (Louw and Theron, 2012). Harvest maturity greatly influences the post-harvest storability and potential shelf-life (Crisosto et al., 2008; Usenik et al., 2014) and may be directly and indirectly affected by the pre-harvest canopy light environment (Murray et al., 2005). Most Japanese plum cultivars that are subjected to prolonged periods of cold storage develop chilling injuries such as gel breakdown (GB), internal browning (IB) and aerated tissues (AT) (Jooste, 2012). Conditions while still on the tree predispose fruit to develop internal disorders port-harvest, with certain cultivars being more prone to certain disorders, but can mostly be prevented by optimal cold storage (Jooste, 2012). Gel breakdown is a brown gelatinous breakdown surrounding the mesocarp that occurs in mature fruit, while IB manifests in the outer layers underneath the peel as a brown area with loss of juiciness in less mature fruit (Jooste, 2012). Aerated tissue manifests as dry flesh with a whitish appearance (Jooste, 2012). Broken stones (BS) develop in certain cultivars and manifests as either stones which split open near the stylar-end, or cracked anywhere along the stone resulting in detached pieces of the stone within the fruit flesh (Kritzinger et al., 2017). Kritzinger et al. (2017) found that the occurrence of BS in Japanese plums was an interaction between the susceptibility of a cultivar, fruit growth rate during phase II of fruit growth, the orchard environment, and cultural practices. The stones break due to the strong pulling forces exerted by fast increases in fruit radial growth (Hartmann and Neumüller, 2009). The stones break at the point of contrasting density, as stones harden from one end to the other (Kritzinger et al., 2017). Kritzinger et al. (2017) found that 'Laetitia' plums are highly susceptible to BS, and stones started breaking 35 days after full bloom (dafb) when stone lignification was first observed along with an increase in fruit radial growth. In the less susceptible 'Songold', fruit radial growth rate was quicker, but the first signs of BS occurred 42 dafb in the 2013/2014 season. In both cultivars, it occurred later in the following season in both cultivars which emphasizing the interaction with the environment (Kritzinger et al., 2017).

Fruit color is an important factor to consider when changing management practices, as consumers are influenced by the appearance of fruit (McGuire, 1992). Fruit color can also be used a maturity index in certain cultivars some fruit (Steyn, 2012). Fruit color development occurs when chlorophyll degrades and carotenoids, anthocyanins and betalains accumulate to varying degrees. Blue, purple and black colors are mostly due to anthocyanin accumulation such as in 'Midnight Gold' plums, while yellow, orange and red colors are due to carotenoid accumulation in fruit peel and flash, such as in 'Larry Ann' plums. Anthocyanin synthesis is light sensitive in various temperate and subtropical fruit for red peel color development (Steyn, 2012), thus shading by use of nets or incorrect pruning may influence fruit peel color development. The hue angle of plum fruit depends on irradiance where very low levels of light will hinder hue development, but the potential of hue to decrease (become redder) increases with increased cold storage periods (Murray et al., 2005). The general trend found in literature is a decrease in red color development in fruit under protective nets, e.g. apple (Amarante et al., 2011; Dussi et al., 2005; Mupambi et al., 2017) and plums (Murray et al., 2005).

Sunburn is a physiological disorder of the fruit causing visible symptoms such as peel discoloration and or necrosis and is a leading cause of poor fruit quality. When fruit is exposed to relatively high temperatures and irradiance levels for extended periods of time, the fruit surface temperature (FST) increases to a point where cells experience oxidative damage, and or even killed, and symptoms usually appear or worsen during fruit cold storage (Dussi et al., 2005; Rackso and Schrader, 2012). McClymont et al. (2016) reported FSTs in red blushed 'Deliza' pears reached 45 ºC when air temperatures were a minimum of 28.5 ºC, and up to 50 ºC when air temperatures were 38 ºC in Australia. McClymont et al. (2016) also reported that between 09h00 and 10h00, FSTs had already reached 44 ºC, and by 11h00 the FST reached 49 ºC (McClymont et al., 2016). Determining the threshold temperature of a fruit where sunburn damage would occur is often difficult as FSTs that lead to sunburn and those that do not often overlap as differences within the tree exist, and sunburn symptoms may appear days or even weeks later, thus the duration of temperatures exceeding the threshold also play a role (McClymont et al., 2016). Nets generally modify the underlying microclimate by decreasing wind speed and diurnal temperature fluctuations due to reduced radiant heat under the nets, increased relative humidity (RH), and lowering of the atmospheric water demand and leaf evapotranspiration rates (Amarante et al., 2011; Middleton and McWaters, 2002), and therefore potentially eliminate severe sunburn damage to fruit by avoiding temperatures reaching threshold values. On the other hand, bee activity is highly dependent on the environment, especially weather conditions with increasing activity in warmer conditions, but very hot weather may also decrease activity (Goodwin, 2012; Middleton and McWaters, 2000). Bees prefer open skies and net coverings may reduce activity due to changes in light, temperature, RH, or they may simply become tangled in the nets (Goodwin, 2012).

The purpose of this study was to determine the effects of permanent white shade netting on the yield and fruit quality of two Japanese plum cultivars ‘Larry Ann’ and ‘Midnight Gold’ at harvest, as well as assess the quality of the fruit after six weeks cold storage and a one week shelf-life.

Materials and Methods

Plant material and site description. The trials were conducted over two growing seasons, 2016/2017 and 2017/2018, at Excelsior farm (33°64’99.797’’, 19°53’81.901’’ E) between Worcester and Robertson in the Western Cape province, South Africa (Fig. 1). Two commercial plum cultivars were selected, viz. ‘Larry Ann’, a yellow flesh plum with a yellow ground color and red over color, and ‘Midnight Gold’, a yellow flesh plum with a dark purple-blue peel color. ‘Larry Ann’ trees on Viking rootstock were planted in 2013 at a spacing of 1.5 x 3.5 m. Micro irrigation was used in the orchard. Cross pollinators used for ‘Larry Ann’ consist of 10% ‘Laetitia’ and 10% ‘Angelino’. The ‘Midnight Gold’ trees on Mariana rootstocks were planted in 2014, at a spacing of 1.5 x 3.5 m. Cross pollinators used for ‘Midnight Gold’ consisted of two rows of ‘Midnight Gold’ alternating with two rows of ‘August Yummy’, and the ‘August Yummy’ rows include 10% ‘Angelino’.

Treatments and experimental design. The trial compared fruit from underneath the shade net to fruit from trees outside the net in full sun. The net is a 20% crystal white shade net (Knittex, Multiknit Pty Ltd, 2017) with a permanent flat structure that was installed in 2015 over half the orchard covering half of each cultivar block 1.5m above the treetops (Fig. 1 and 2). The outside areas of the orchard were not covered by any nets and no side-nets were present. Ten replications consisting of two- or three-tree plots were selected in a row under the nets vs. ten replicates outside the nets. In the 2017/2018 season, fruit set for 'Larry Ann' was extremely low and therefore three-tree plots were selected, while two-tree plots were used the previous season.

Sampling and storage methods. At the main commercial harvest date for each cultivar (Table 1 and 2), three cartons each with 50 fruit, were picked per replication. The remaining fruit from the plots were strip picked and weighed to determine the total yield of fruit per tree. After harvest, tree trunk circumference was measured just above the graft union, and the average yield between the two-tree plots converted into yield per cm^2 trunk cross-sectional area (TCSA) was used to determine yield efficiency. The harvested fruit were brought to the laboratory at the Department of Horticultural Science at Stellenbosch University in their respective cartons. The first set of 10 cartons (one per replication) were subjected to standard maturity indexing (MI) as described below and the two remaining sets of cartons were placed into regular atmosphere cold storage for six weeks at -0.5 ºC. After six weeks cold storage, one carton from each replication was used for standard MI measurements as well as analysis of internal disorders, shrivel and fruit decay. The remaining set of 10 replicates were placed into a 10 ºC cold storage simulating shelf-life for one week. After one-week shelf-life the third set of cartons was analyzed the same way as the previous set. The same procedure was followed for both seasons, 2016/2017 and 2017/2018.

Maturity indexing and disorder data collected. The non-destructive measurements at harvest consisted of the following: (1) Fruit mass, diameter and length using an electronic balance and a digital caliper (Mitutoyo Corp., Kanagawa, Japan), (2) Fruit color, which consisted of the hue angle, lightness and chroma, measured on opposite cheeks using a handheld electronic colorimeter (NR-3000, Nippon Denshoku, Tokyo, Japan). If a negative hue angle were obtained, the data were transformed by adding 360 to obtain a positive value between 0 and 360º of the color wheel (McGuire, 1992).

Sunburn was assessed visually on a scale of 0 to 5, where 0 showed no signs of sunburn and 5 had sunburn necrosis, according to a chart developed for 'African Delight' plums (Fig 3A). Wind damage was scored on a scale of 0 to 8, where 0 showed no signs of damage and 8 had severe peel damage, using wind damage score chart PL3 developed for 'Santa Rosa' plum (Unifruco Research Services, Deciduous Fruit Chart PL. 3) (Fig 3B). Sunburn and wind damage were recorded as the percentage of fruit out of 50 with damage, and the severity of the damage expressed according to the specific scale used. After six weeks cold storage and one-week shelf-life the external appearance of the fruit was visually assessed for shrivel and decay, where shrivel would be a wrinkled appearance of the peel, and decay would be the presence of mold, both recorded as either present or absent. The decay-causing pathogen(s) were not determined.

Destructive maturity measurements consisted of determining flesh firmness on pared opposite cheeks of the fruit using a penetrometer (Fruit Texture Analyser; GÜSS Manufacturing (Pty) Ltd., Strand, South Africa) fitted with an 11 mm tip as prescribed for plums in South Africa. Fruit were then cut open and visually assessed for internal disorders such as IB, GB, AT and BS. Slices of fruit were then cut from opposite sides of the fruit of 25 randomly selected fruit from each replicate and juiced together to determine TSS concentration using a handheld refractometer (Atago PR-100 9501, ATAGO Co. Ltd., Tokyo, Japan) and TA analysis by titration with 0.1M NaOH with an automated titrator (888 Tritrando and Robotic USB sample processor XL, Metrohm Ltd., Herisau, Switzerland). Data were expressed as a percentage of malic acid (g 100 g^{-1} juice).

Additional measurements and observations. In the 2017/2018 season the air and soil temperatures were measured every 30 minutes using automated Tinytag data loggers (Tinytag, Gemini Data Loggers, United Kingdom), with two loggers placed outside the nets hanging in two randomly selected trees towards the shaded position within the canopy, and two in the control block and under the nets towards the middle of the row from 06 September 2017 to 05 May 2018, and the monthly average was calculated. Irradiance measurements using a quantum sensor attached to a light meter (LI-250; LI-COR, Lincoln, NET) were done on 30 October 2017 around 11:30 am under the nets and outside under the full sun, with the sensor orientated towards the sun.

At a second observational trial site at Sandrivier farm, situated near Wellington, Western Cape province, South Africa (-33.644689 S. 19.006487 E), bee activity in three blocks of 'African Delight' plums under the nets were observed and compared to two uncovered blocks, where one hive was randomly selected per block. The trees were covered with a 20% white shade net (Knittex, Multiknit Pty Ltd, 2017) set up as a permanent flat structure, and the west side was closed with green netting. Tree spacing was 3.5 x 1.0 m, and trees were analyzed at 90% full bloom stage. Observations were done from ca.10:00 until 12:00 in the morning, on two days, 30 August and 1 September 2017. The hives were placed at the end of every third row facing towards the tree row in a south-east direction. The hives were placed under the nets, approximately 10 m from the entrance of the rows. Bee activity was observed at three randomly selected hives by sitting approximately 3 to 5 m from a hive and the number of bees that flew from the hive to the trees under the nets, and those that flew away from the net structure to other food sources nearby were counted. Two trees were tagged in each block, one 15 m and another 50 m from the hive in the same row. Bee activity was observed and recorded as a total number of bees seen on the blossoms over a five-minute period at the respective trees. Observations were repeated every 20 to 30 minutes for an average of two hours over two consecutive days, at the selected hives both under the nets and outside the nets. Air temperature and RH were recorded outside and under the nets.

Statistical analysis. The data were analyzed using the General Linear Models (GLM) and One-Way ANOVA procedure of SAS Enterprise Guide 7.1 (SAS Institute Inc., Cary, North Carolina, USA) as a complete randomized statistical design with two treatments and ten replications. A pair-wise *t* test was used to determine Fischer's Least Significant Difference (LSD) between the means when the F-statistic indicated a significance at $P<0.05$.

Results

<u>'Larry Ann'</u>

'Larry Ann' 2016/2017 season: The average yield per tree did not differ between the trees under nets and the controls trees in full sun, but the yield efficiency was lower under the nets (Table 3). Fruit size (mass, diameter, and length) was significantly reduced under the nets compared to the uncovered control fruit (Table 4). Fruit firmness decreased with increasing storage period and shelf-life but no significant differences in firmness were seen between treatments over the storage period (Table 5).

The fruit TSS and TA did not differ at harvest between netted and non-netted trees (Table 6). The hue angle and chroma of the plums did not differ significantly between treatments, whilst plums harvest from under the nets were slightly lighter than those from under full sun (Table 6). After six weeks cold storage at -0.5 ºC, still no significant differences were found in fruit TSS and TA, however nets reduced chroma and increased the lightness compared to fruit harvested under full sun, and hue was unaffected (Table 7). After shelf-life of one week at 10 ºC, TA was significantly higher in non-netted fruit (Table 8). The nets reduced the chroma and increased the lightness readings taken after the shelf-life period, while hue remained unaffected (Table 8).

A significantly higher percentage of control fruit showed wind damage compared to the fruit from under the nets, but the severity of wind damage did not differ on affected fruit. No significant differences were found in sunburn damage in 'Larry Ann' fruit (Table 9).

After six weeks cold storage, very few disorders were found, with no significant differences between netted and non-netted trees in IB, GB, AT or shrivel. The percentage of fruit with decay was low but significantly higher in the control than in the netted fruit (Table 10). After the one-week shelf-life, fruit from under the nets had a significantly higher incidence of IB, while control fruit had almost three times the percentage GB compared to fruit from under the nets. No differences were found in AT, shrivel, BS or decay between control and netted trees (Table 11).

'Larry Ann' 2017/2018 season: During the 2017/2018 season, the average yield per tree was significantly higher in the control trees compared to the trees under nets, but the difference in yield efficiency was not significant. The average fruit size did not differ between control and shaded fruit for 'Larry Ann'. Fruit firmness at harvest and after six weeks cold storage at 0.5 ºC, was significantly higher in control fruit compared to netted fruit, but the difference was not significant after one week shelf-life (Table 14). Firmness decreased rapidly after the storage at shelf life conditions for one week.

Fruit TSS and TA were significantly higher in fruit from the control trees than in fruit from under the nets (Table 15). Differences in fruit color measurements were not significant between control and netted fruit for chroma and hue angle, but a significant difference was found in fruit lightness, where netted fruit had lower values than control fruit (Table 15). After six weeks cold storage no significant differences were found in the average TSS and TA, or hue and chroma values, however the netted fruit were significantly lighter than the fruit harvested from under full sun (Table 16). The TA measurements could not be taken after the one week shelf-life due to fruit being overripe (Table 17). There were no significant differences in the TSS concentration between control and netted fruit. Fruit color analyses following the shelf-life storage did not differ significantly in hue or chroma between treatments, however netted fruit remained significantly lighter than control fruit (Table 17).

'Larry Ann' control fruit had significantly more sunburn and wind damage compared to the fruit under nets in the 2017/2018 season although the level of incidence was nearly negligible (Table 18). In addition, the severity of sunburn and wind damage was greater (Table 18) although only a small percentage of fruit had severe sunburn (Fig. 4). During the 2017/2018 season, there were no occurrences of internal disorders, and no significant occurrence in decay in the fruit after six weeks cold storage (Data not shown). After one week of shelf-life at 10 ºC, control fruit had a very low occurrence, but a significantly higher percentage of GB than the fruit from under the nets. Postharvest decay was also very low and did not differ significantly between fruit from netted and control trees (Table 19).

'Midnight Gold'

'Midnight Gold' 2016/2017 season: During the 2016/2017 season, both the yield and yield efficiency did not differ significantly between the 'Midnight Gold' control trees and trees under nets (Table 20) and neither did fruit size (Table 21). Non-significant differences were found in firmness measurements between the control and netted fruit at all three stages of evaluation (Table 22). A gradual decrease in firmness was observed with increasing storage period.

At harvest, TSS was higher in the control fruit compared to netted fruit, while TA was higher in the netted fruit compared to the control fruit (Table 23). Control fruit exposed to full sun had significantly higher chroma, hue and lightness values compared to the fruit from under the nets (Table 23). After six weeks cold storage at -0.5 ºC, fruit TA did not differ significantly, while TSS was still significantly higher in the control fruit compared to the fruit from under the nets (Table 24). The color differences after six weeks cold storage were opposite to the harvest group, where fruit from under the nets had significantly higher chroma, hue and lightness values compared to the controls (Table 24). After shelf-life of one week at 10 ºC, fruit TSS and TA did not differ significantly between the control and netted fruit (Table 25), while only chroma of the fruit from under the nets was reduced compared to the fruit harvested under full sun (Table 25).

The percentage of fruit with sunburn was very low and did not differ between open and netted trees (Table 26). The few control fruit with sunburn, however, had significantly higher sunburn severity scores. The percentage of wind-damaged fruit was significantly higher in open trees, but the intensity of wind damage did not differ (Table 26). The severity of wind damage ranged from no damage to very severe damage in a single sample (Fig. 5).

The average percentage of postharvest internal disorders did not differ between control fruit and fruit from under the nets, with no signs of shrivel or decay after six weeks cold storage (Table 27). After one-week shelf-life at 10 ºC, fruit from under the nets had significantly higher percentages, albeit very low levels of IB and GB, while differences in AT and decay were not significant between the control and netted fruit (Table 28; Fig. 6.).

'Midnight Gold' 2017/2018 season: During the 2017/2018 season, the control trees had a significantly higher average yield and yield efficiency per tree compared to netted trees (Table 29). The average fruit mass and diameter were significantly larger in the control fruit compared to the netted fruit, while no significant differences were found in fruit length (Table 30).

The control fruit was significantly firmer at harvest than the fruit from under the nets and remained firmer after six weeks cold storage and after one week shelf-life. Fruit firmness decreased slightly during the six weeks cold storage, but a large reduction in firmness was found in fruit after one week at 10 ºC (Table 31). At harvest, the control fruit had a higher TA (Table 32). Total soluble sugars data was unavailable for analysis as the juice was discarded by mistake. From harvest throughout cold storage, control fruit had significantly higher chroma and lightness values compared to the fruit from under the nets, while differences in hue angle were not significant (Table 32, 33 and 34). After six weeks cold storage TSS and TA of control fruit were higher than that of netted fruit (Table 32). After one-week shelf-life at 10 ºC, control fruit had significantly higher TSS compared to the fruit from under the nets. After 6 weeks, fruit were overripe and fruit juice titrations were not possible (Table 34).

A significantly higher percentage control fruit had wind damage and the average wind damage severity was higher compared to netted fruit, but no significant differences were found in sunburn damage to ‘Midnight Gold’ fruits (Table 35). After six weeks cold storage only 2% of the control fruit had at AT while no other internal disorders were visible in either the control or netted fruit (Table 36). After one-week shelf-life, control fruit had significantly higher AT compared to the netted fruit, whilst no significant differences were seen in the percentage of fruit with BS nor decay and no GB, IB or shrivel occurred (Table 37).

Additional measurements and observations. Light readings under the white shade nets were on average 288.7 $\mu mol \cdot m^{-2} \cdot s^{-1}$, or 13.9% less than in the open (Fig. 7). Air temperature differences were very small, but mostly lower under the nets (Fig. 8), and RH was on average slightly higher under the nets (Fig. 9). Soil temperatures under the nets were slightly higher from November 2017 until May 2018 (Fig. 9).

Bee activity at the hives on Sandrivier on 30 August 2017 was higher in full sun (control), with a large number of bees exiting the hives, but none were flying into the rows towards the trees in full sun, except one bee at the tree nearest to the hive (Table 38). The air temperature in the morning at 10:25 was higher than at 11:10 due to it becoming overcast, and wind increased, which was reflected in the decrease in the number of bees exiting the hive. Relative humidity also increased with increasing cloud cover. Under the nets, fewer bees exited each observed hive at 10:30 as well as 11:30 when temperatures were 20.5 °C and 16.6 °C, while a slight increase in activity was seen at 11:00 when temperatures increased to around 25.5 °C for a short period, but no bees were flying towards the trees under the nets (Table 38). On 1 September 2017, bee activity was slightly higher compared to 30 August 2017 as the skies were clear with little to no wind (Table 39). In the control block in full sun the number of bees that left the hives at all three times during the morning was relatively high, but still, few were seen flying towards the trees and were present in the tagged trees at 5 or 10 m distance from the hive. Temperatures rose from 20 to 27 °C while RH decreased from around 60 to 42% under full sun. Under the nets the number of bees exiting the hives was fewer in the early morning, but increased towards midday with more bees exiting the hives compared to the control. There were also more bees seen flying in the two tagged trees compared to the control. Temperatures and RH remained lower under the nets compared to under full sun.

Discussion

In our trials, the mean difference in air temperatures was ca. 1 ºC lower under nets compared to open-air, possibly due to the net structure having open sides and only covering a relatively small area of the orchard. Kalcsits et al. (2017) reported that daily mean air temperatures and canopy RH did not differ between any of the photoselective nets compared to the control, but the soil temperatures under the various photoselective nets were consistently higher throughout the season, which may be beneficial for root microenvironment. In general, RH is often higher under nets, and more so if the sides are closed or net thread density is high, as air movement is reduced, and the water vapor transpired by the trees is not mixed with outside dry air as much as if there were no net covering (Stamps, 2009). Murray et al. (2005) also reported reduced air temperatures under nets, with 50% shade nets having slightly higher temperatures than the 20% shade nets due to less air movement.

One of the main reasons for installing nets over fruit orchards is to protect the fruit from adverse climatic conditions that may cause damage and decrease marketable yield (Castellano et al., 2008; Solomakhin and Blanke, 2010). We found significant reductions in wind damage in 'Midnight Gold' especially in the second season, but also in 'Larry Ann', which would have been commercially significant, increased the pack-out percentage of Class 1 fruit. The reduced wind damage can be explained by the reduced wind speed under the nets (Blanke, 2009). Wind speed is physically reduced by nets and reduces tree and branch movement and ultimately scuff marks on fruit (Middleton and McWaters, 2002). Kalcsits et al. (2017) noted a 40% reduction in wind speed in a 'Honeycrisp' apple orchard in which the nets reduced light transmission by approximately 20-23% compared to the open orchard. In this orchard scuff marks on apples were significantly reduced by the presence of nets.

The 20% crystal white shade nets reduced the average PAR reaching the trees by 13.9% (Fig. 7). Kalcsits et al. (2017) reported an average of 20% light reduction under three different photoselective nets, while Amarante et al. (2011) reported an average reduction of 18.4 % under 20% nets, and Blanke (2009) reported reduced PAR of 8.4% under new crystal white nets with large mesh size (3 x 9 mm), 10.7% under red-white nets, 11.6% under grey nets, 13% under green-white nets, 15.6% under green-black and 16.1% reduction under black nets with narrow mesh size (2.5 x 6.5 mm). In both seasons and for both cultivars very little sunburn was present even outside the nets, but in one season on 'Larry Ann' the percentage of fruit with sunburn was significantly reduced from 1.4 to 0.1%. Therefore, very little can be said about the effect of nets on sunburn in Japanese plums. However, these cultivars are not considered susceptible to sunburn and results may be different for a more sunburn prone cultivar like 'African Delight' (Makeredza, 2019). It is important to remember that the average reduction in light is dependent on weather conditions over periods of time, which differ during the season as prolonged cloudy or sunny days occur at different times during fruit growth and development periods (Middleton and McWaters, 2002), which could help explain the seasonal differences in fruit quality. High irradiance during the full bloom and or pollination period will not negatively affect the yield or fruit quality as bee activity is increased, but near harvest, fruit may be more susceptible to sunburn (Basile et al., 2012, 2014; Middleton and McWaters, 2002). Reduced PAR and air temperatures under the nets lowers fruit FSTs (Rackso and Schrader, 2012), which explains the lower number and severity of sunburnt fruit and the severity of sunburn under nets, albeit generally low numbers of fruit with sunburn were recorded in our trials.

In the 2016/2017 season, 'Larry Ann' yield efficiency and fruit size were decreased under the 20% white shade nets compared to the control, and in the 2017/2018 season, the average yield and yield efficiency was also decreased by nets without an effect on fruit size. The total yield per tree for 'Larry Ann' was around half of the 2016/2017 season for both the control and netted trees, with 20.4 and 21 kg per tree in 2016/2017 and 10.1 and 7.9 kg per tree in the 2017/2018 season, respectively. This decrease in yield in 'Larry Ann' was independent of the netting. 'Midnight Gold' yield and yield efficiency showed no significant differences between the control and netted trees during the 2016/2017 season, while in the 2017/2018 yield and yield efficiency was significantly lower under the white shade nets. Basile et al. (2012) found that kiwi vines under various colored nets had decreased yields and increased fruit size, although this was not the case for the white nets. Girona et al. (2012) also reported a lower yield in peaches under nets compared to non-netted controls, as well as a lower return bloom and fruit set the following season. However, Štampar et al. (2001) found that both black and white nets (shading percentage not stated) did not reduce yield in 'Elstar' apples. Middleton and McWaters (2000) found hail nets had relatively little effect on the yield of apples.

As mentioned earlier, in our trials yield was either unaffected or decreased by the nets. The reduction in yield can be due to various reasons. Yield is determined by the success of pollination and fruit set of flowers. All Japanese plums are diploid, and most of them, including the two cultivars used in our trials, require cross-pollination (Hartmann and Neumüller, 2009). Cross-pollination of fruit trees in South Africa is primarily dependent on bees that are highly dependent on environmental conditions (Middleton and McWaters, 2002). Middleton and McWaters (2000) found an insignificant decrease in fruit set in apple trees under nets towards the inner part of the orchard where bee activity was lower compared to the outer edges, which could be a factor influencing uniform fruit set under nets when relating to bee activity, although overall yield was unaffected. At Sandrivier, bee activity observed under the nets was lower when outside temperatures were low compared to the open block in full sun, but activity was higher when outside temperatures were high, indicating the dependence of bee activity on temperature. The first day of observation (30/08/2017) was cloudy, with about 70-80% cloud cover around 10:00 and by 11:30 it was completely overcast, and wind speed was minimal and bee activity was low around the hives. This is confirmed by Middleton and McWaters (2000), who observed minimal bee activity on wet or drizzly days compared to warm sunny days in apple orchards in Australia. The second day was warmer with sunny skies, and bees became active earlier in the morning with more bee activity observed under the nets compared to the uncovered blocks as temperatures increased. The trees were also in full bloom on day two, and the bees spent longer periods at each flower compared to the previous day (personal observation), but there were still a large number of bees flying outside of the net structure. By midday, there was less bee activity than earlier in the day, both under nets and outside the nets. Middleton and McWaters (2000) also noted a general decline in bee activity towards midday. A number of bees were seen trapped in the corners as well as on top of the net structure on the outside. The further the distance from the hive, the less bee activity was observed, as was reported by Middleton and McWaters (2000). The low number of bees observed at the two tagged trees in each block is a poor representation of the whole block, but on those two days, it was clear that the weather had more of an influence on bee activity than the net.

Fruit set is also influenced by shoot growth competition. The decrease in incident light and PAR transmission caused by nets favors stronger vegetative growth, thus increasing sink strength of vegetative growth that reduces fruit set and therefore crop load (Basile et al., 2012; Blanke, 2009; Stamps, 2009). We did not monitor vegetative growth in this trial, but results from the same trial can be viewed in Paper 2, however, from personal observation in the selected rows of this trial, it is clear that trees were more vigorous under the nets. Return bloom can be lower under nets due to numerous environmental and tree growth factors such as increased gibberellin levels (Girona et al., 2012), thus resulting in potentially fewer flowers setting. According to Girona et al. (2012) this was due to fewer reserves and stronger vegetative growth under resulting in a lower yield of smaller fruit in peach trees.

A lower yield often results in larger fruit (Amarante et al., 2011; Middleton and McWaters, 2002; Štampar et al., 2001; Stamps, 2009), but in our trials this was not the case as 'Mighnight Gold' fruit decreased in weight and diameter under the nets. Murray et al. (2005) reported a decrease in fruit size of 'Laetitia' plums under 20% shade nets. Murray et al. (2005) noted that the long-term shading negatively affected plum fruit carbohydrate availability regardless of improved tree water status resulting in decreased fruit size in both 'Laetitia' and 'Songold'.

In the 2016/2017 season, the firmness of 'Larry Ann' and 'Midnight Gold' fruit was not affected by the shade nets at harvest, after cold storage or after shelf life. In the 2017/2018 season, 'Larry Ann' and 'Midnight Gold' control fruit were firmer than fruit from under the nets when determined at harvest, possibly indicating a slightly advanced maturity under the nets. In contrast, Amarante et al. (2011) reported fruit firmness in 'Gala' and 'Fuji' apples under 18.5% white nets was higher at harvest than non-shaded fruit, but after four months cold storage and one-week shelf-life at 20 °C, both cultivars from under the nets were less firm than fruit from the uncovered trees.

The TSS concentration and TA percentage of 'Larry Ann' were not affected by the nets at harvest, while lower hue angle and lightness developed under nets. The TSS in netted 'Midnight Gold' plums at harvest was lower than the controls in the first season, while TA was higher in netted fruit at harvest, and although these differences were statistically different, one would not taste the small differences between the two. Murray et al. (2005) reported fruit under nets to be consistently less mature than sun-exposed fruit, with reduced TSS in 'Songold' and 'Laetitia' due to reduced carbohydrate activity within trees under nets. However, Middleton and McWaters (2002) suggested that accurately quantifying TSS in fruit from under nets is complex as fruit size and canopy position can greatly influence TSS. Basile et al. (2012) found kiwifruit under grey, red and white nets had higher TSS compared to fruit under blue nets or controls under open field conditions, while control fruit also had the highest TA compared to all the netted fruit. In the second season, both the TSS and TA of 'Larry Ann' plums were reduced by the shade nets at harvest, while in 'Midnight Gold' only the TA was reduced by the nets.

After six weeks cold storage, the firmness of both 'Larry Ann' and 'Midnight Gold' was unaffected by the shade nets in the 2016/2017 season, while in the 2017/2018 season, the firmness of both cultivars from under the nets was reduced. The lower firmness in netted fruit after storage was probably due to fewer structural and storage carbohydrates that formed in fruit whilst on the trees under nets, as suggested by Amarante et al. (2011) for apples. Although not significant, it is interesting to note that the firmness of 'Larry Ann' reduced much faster in fruit from under the nets compared to the controls during cold storage. After one-week shelf life, 'Larry Ann' fruit firmness did not differ from the controls in both seasons, while in 'Midnight Gold' only the fruit from the second season's harvest differed, with the control fruit firmer than fruit from under the nets. A similar trend was found for avocado fruit grown under 20% white and blue nets, where 80 and 75% of the harvest was "ripe and ready to eat" (firmness <10 N) after five days at shelf-life conditions, compared to only 40% from the open field (Tinyane et el., 2018). However in the case of 20% red nets, it was 0% that were "ripe and ready to eat". Solomakhin and Blanke (2010) found that apple fruit firmness was more dependent on the net color, where both 'Pinova' and 'Fuji' apples grown under green-black and red-black nets were softer than those from red-white and white nets, while non-shaded apples were found to be firmer than all the netted fruit at harvest. Murray et al. (2005) found that with an increase in shade net percentage, firmness of both 'Laetitia' and 'Songold' plums decreased when determined at harvest, but during cold storage which simulated commercial export conditions from South Africa, firmness decreased rapidly in both cultivars, but more so in shaded fruit compared to unshaded controls, which was the common trend in our trials and majority of the literature.

The TSS and TA of 'Larry Ann' was not affected after six weeks cold storage by the nets in both seasons, while in 'Midnight Gold' the shaded fruit had lower TSS after six weeks of cold storage in both seasons, and in addition in the second season, the TA was lower in shaded fruit compared to the controls. The reduction in TSS confirms the trend in various deciduous fruit types grown under nets (Girona et al., 2012; Middleton and McWaters, 2002; Murray et al., 2005), and after cold storage, TSS either remains lower in netted fruit (Murray et al., 2005), or does not differ from controls (Girona et al., 2012), which both were applicable in our trials depending on the cultivar. On the contrary, Basile et al. (2012) found white nets produced kiwifruit with the highest TSS and TA at harvest, but after three months cold storage the differences were no longer significant.

'Larry Ann' and 'Midnight Gold' responded differently to the shade nets with regards to color development, where the hue angle was generally unaffected in both cultivars with the exception of 'Midnight Gold' harvest and shelf-life fruit whereby the nets reduced the hue angles of the fruit. 'Larry Ann' fruit generally had an increase in lightness under the nets, with one exception where fruit harvested in the second season from under nets were darker. Chlorophyll breaks down in maturing fruit as the synthesis of various color pigments occur (Steyn, 2012) but the presence of shade nets might have also reduced the rate of chlorophyll breakdown, altering the balance of chlorophyll to color forming pigments. It is therefore possible that less pigment formed under the nets resulting in lighter fruit with reduced chroma, as the reduction in chroma was a common result in both cultivars. Makeredza (2019) reported no significant changes in red color development in 'African Delight' plums under 20% black and white shade nets, similar to our findings on hue that remained generally unaffected. The increase in lightness and decrease in chroma can be explained by the balance of anthocyanins and chlorophyll in the fruit peels, which tend to both increase under shade, resulting in a duller red color (Steyn, 2012).

Physiological disorders are often induced pre-harvest and can be prevented, maintained or worsened during and or after cold storage (Jooste, 2012; Murray et al., 2005). After six weeks cold storage, 'Larry Ann' fruit from under the nets had significantly less decay (2.8%) compared to the controls (7.2%) in the first season, whilst the internal disorders in 'Midnight Gold' fruit were not affected by the nets. In the second season, 'Larry Ann' was not affected after six weeks cold storage, but the 'Midnight Gold' controls developed a little AT (2% of fruit) compared to none in the netted fruit. Murray et al. (2005) did not find any internal disorders on either 'Laetitia' or 'Songold' plums and related this to the possible storage period being too short, as fruit was stored for only 10 days at -0.5 ºC followed by eight days at 7.5 ºC then 7 days at 15 ºC.

Cold storage beyond seven weeks adversely affects plum quality as plums are highly perishable due to their high respiration rates, and develop CI under prolonged cold temperatures (Jooste, 2012). In our trials, the occurrence of internal disorders after one week shelf-life was greater overall compared to that after of six weeks cold storage, albeit numbers were generally low. After one-week shelf life, 29% of netted 'Larry Ann' netted plums had IB, 9.1% had GB and only 4% showed signs of decay, compared to the controls of which 11.8% had IB, 31.8% had GB and 2.4% had decay setting in, respectively. The higher percentages of IB in netted fruit and GB in controls can be related to fruit maturity and presence of heat shock proteins as mentioned by Jooste et al. (2012), where more mature fruit are more susceptible to GB than less mature fruit. Possible reasons if looking at available literature for netted fruit having more physiological disorders could be due to the fewer structural carbohydrates within the fruit making cell structures more susceptible to damage, as suggested by Amarante et al. (2011), but we did not measure this in our trials, we did however see more IB and less GB, suggesting some relationship between heat shock proteins, fruit maturity and GB. 'Midnight Gold' netted fruit had 1.6% IB, 1% GB and 4.4% AT compared to the controls which showed almost zero internal disorders after one week shelf-life. In the second season, the occurrence of internal disorders was much lower, but control fruit of 'Larry Ann' and 'Midnight Gold' had more GB and AT respectively. Jooste (2012) found significant interactions between storage temperature (-

0.5 ºC), duration (six weeks cold storage and one week and shelf-life at 10 ºC) and harvest maturity (upper and lower end of harvest window) for total occurrences of CI's in Japanese plum 'Sapphire'. Jooste et al. (2012) found that IB in 'Sapphire' plums occurred after three weeks of cold storage plus seven days of shelf-life, and the occurrence increased with increasing storage duration up to six weeks. Regardless of the presence of nets, Japanese plums are sensitive to long periods of cold storage. Sun exposed fruit also develop heat shock proteins, which help fruit tolerate cold storage and thus chilling injuries (Jooste, 2012). Incidences of GB occurred well after the earliest harvested samples were stored at shelf-life temperatures but remained low overall up until four weeks of cold storage followed by shelf-life storage and increased significantly during the last two weeks of cold storage and seven-day shelf-life period (Jooste et al., 2012). Lee et al. (2015) reported no difference in decay development in 'Ponkan' mandarin citrus fruit under 20% white shade nets or those under full sun, while in apples, Amarante et al. (2011) reported a general reduction in postharvest physiological disorders that are common in apples e.g. bitter pit, various diseases, as well as fruit fly damage under nets.

Conclusion

The 20% crystal white shade nets reduced the irradiance by ca. 13.9% on average, and together with the reduction in wind speed under the nets, the air temperature was on average ±3 °C lower and RH slightly higher under the nets. The decrease in direct radiation, temperature and wind speed under the nets had positive effects on the physical appearance of the fruit, as both cultivars experienced less wind damage and to a lesser extent, sunburn. As a result, sunburn and wind damage were reduced over both seasons compared to fruits harvested from trees not under the net, but the overall occurrence of physical damage was low over the two season. Yield, yield efficiency, and fruit size was reduced under nets in 'Larry Ann' in the first season, while in the second season 'Midnight Gold' yield and fruit size were reduced under nets. Firmness and color differences occurred, but commercially these were not of significance. Generally, the netted fruit were slightly more susceptible to post-harvest physiological disorders such as IB, while control were more susceptible to GB and decay. Lastly, we can conclude fruit from under the nets showed less physical damage, without any large effect on internal fruit quality. It is, however, worrying that a decrease in yield and sometimes fruit size can occur. It might be worthwhile to investigate the effect of a retractable netting system that protects fruit until harvest, rather than permanent nets, and to open nets from after harvest when tree reserves are built-up until after or during pollination and fruit set.

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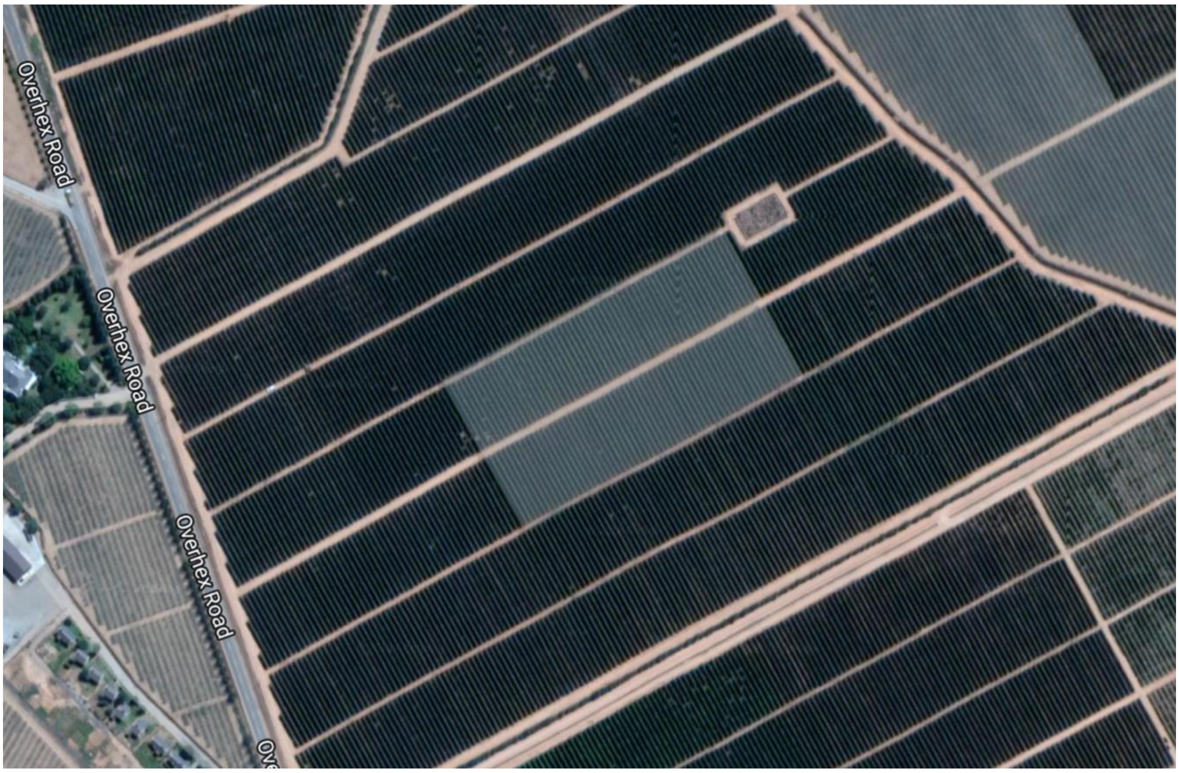

Fig. 1. Trail site at Excelsior farm, between Worcester and Robertson, in the Western Cape Province, South Africa. The shade nets can be clearly seen as the shaded white rectangular area, with the road running directly through the middle. The nets cover a section of 'Larry Ann' and 'Midnight Gold' trees. (Satellite image from Google Maps, URL: https://www.google.com/maps/place/33°38'59.6%22S+19°32'17.2%22E/@-33.6498871,19.5400002,898m/data=!3m1!1e3!4m5!3m4!1s0x0:0x0!8m2!3d-33.6499!4d19.5381)

Fig. 2. Photograph taken at Excelsior farm showing the netting structure. (Photo: N. van Rensburg)

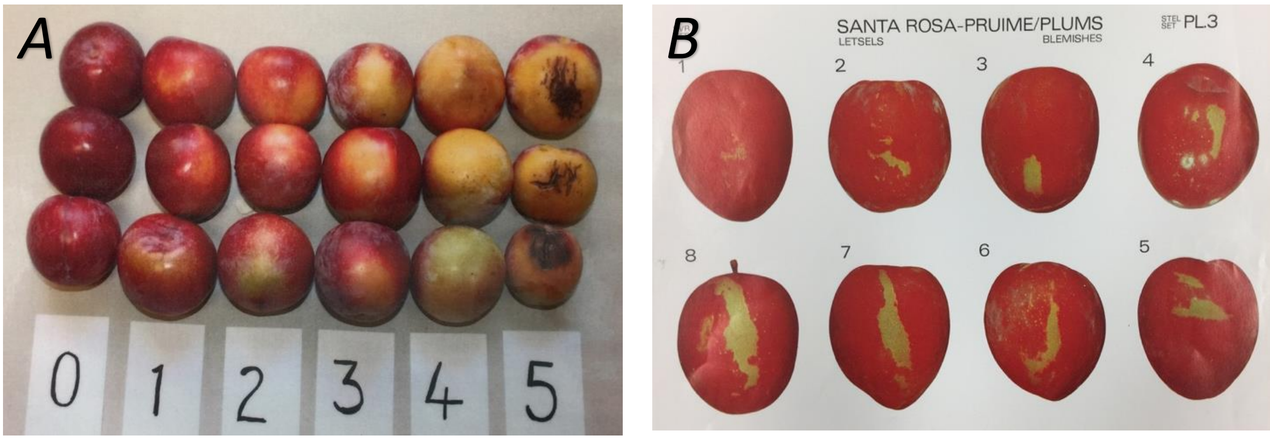

Fig. 3. Example of (A) sunburn damage scale as developed for 'African Delight' (Makaredza) and (B) Unifruco wind damage score chart PL3 developed for 'Santa Rosa' plum.

Fig. 4. Photograpgh of a sample of 'Larry Ann' control fruit with severe sunburn that would be socred as a 5 for severity as it affected the flesh as well. (Photo: N. van Rensburg)

Fig. 5. Photograph of a sample of 'Midnight Gold' plum fruit from the control block showing the severity range of wind damage from one of the two-tree plots. Example of how we scored wind damage severity based on the chart shown in Fig. 3 would be fruit A, B, C, D, E, F, G, and H scored as 0,1, 2, 3, 4, 5, 6, 7, and 8, respectively (Photo: N. van Rensburg)

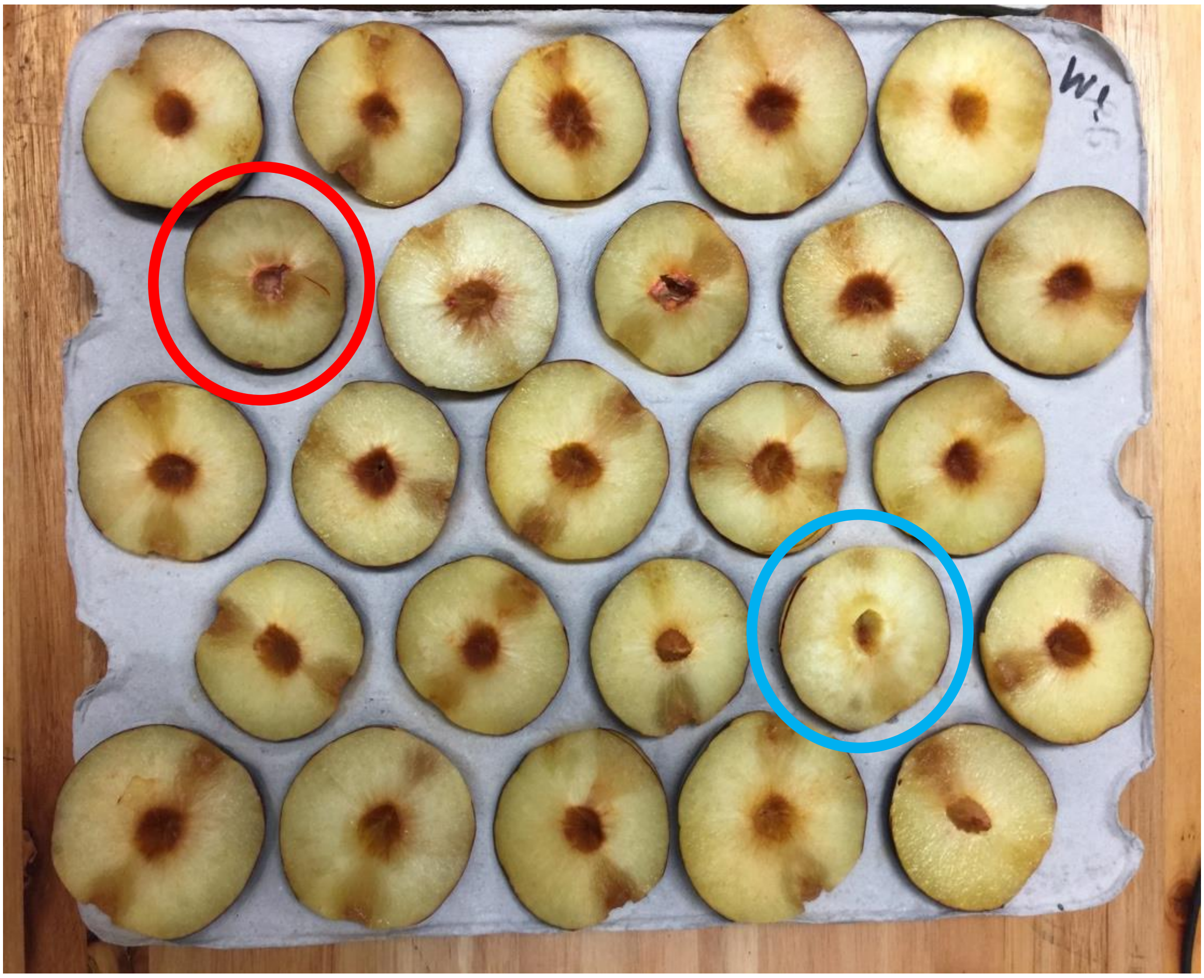

Fig. 6. Photograph of 'Midnight Gold' fruit from under the nets taken after 6 weeks cold storage period to assess for internal disorders. An example of gel breakdown (GB) can be seen in the fruit circled in red, while aerated tissue (AT) is circled in blue. The bruises on each opposite end are from the firmness measurements. (Photo: N. van Rensburg)

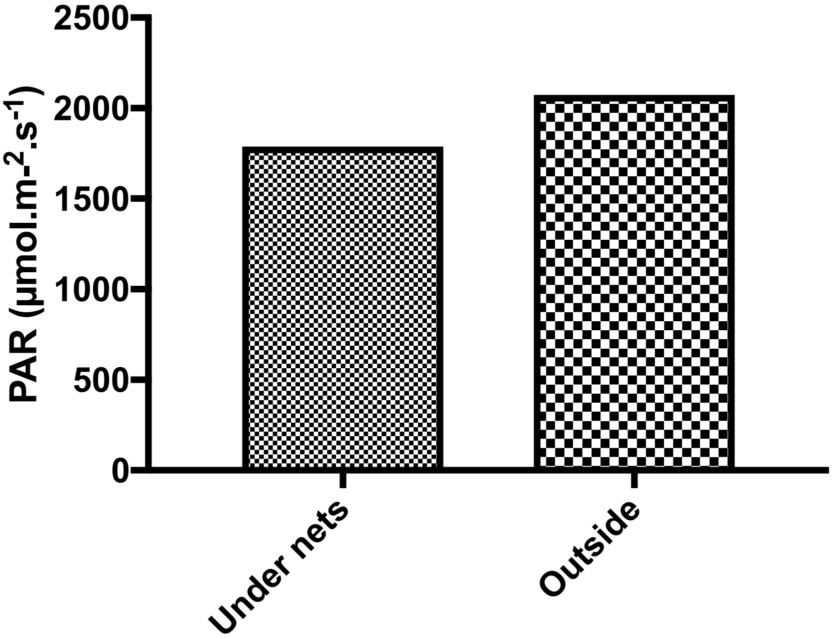

Fig. 7. Bar graph illustrating the effect of shade net on the average irradiance readings measured in PAR under the nets versus outside, taken on 30 October 2017 around 11:30 am, at Excelsior Farm, South Africa.

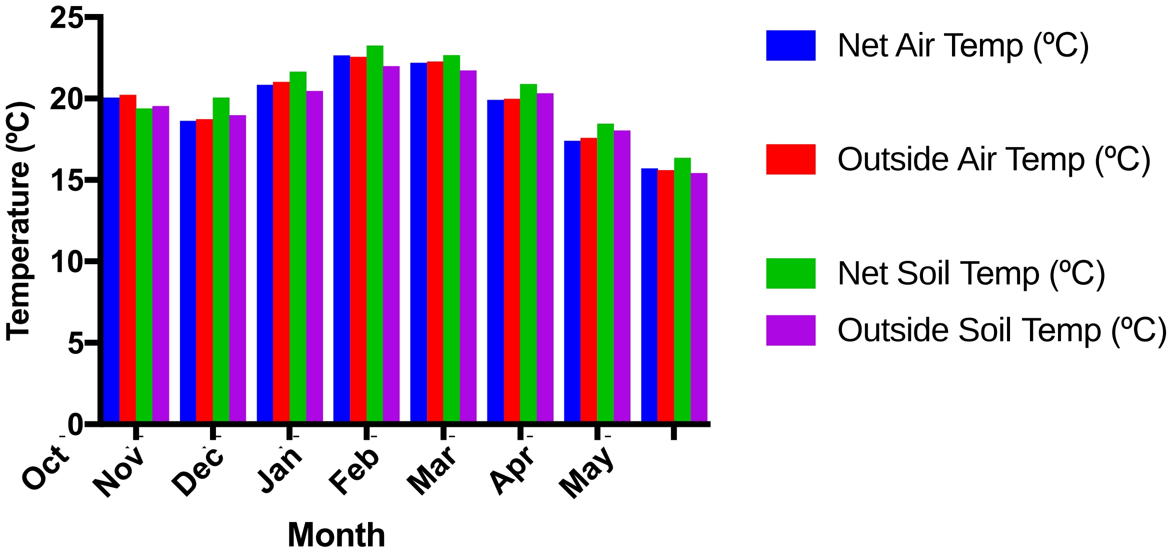

Fig 8. Bar graph illustrating the effect of shade net on the average air and soil temperatures (ºC) measured between October 2017 and May 2018 under the nets and outside, at Excelsior Farm, South Africa.

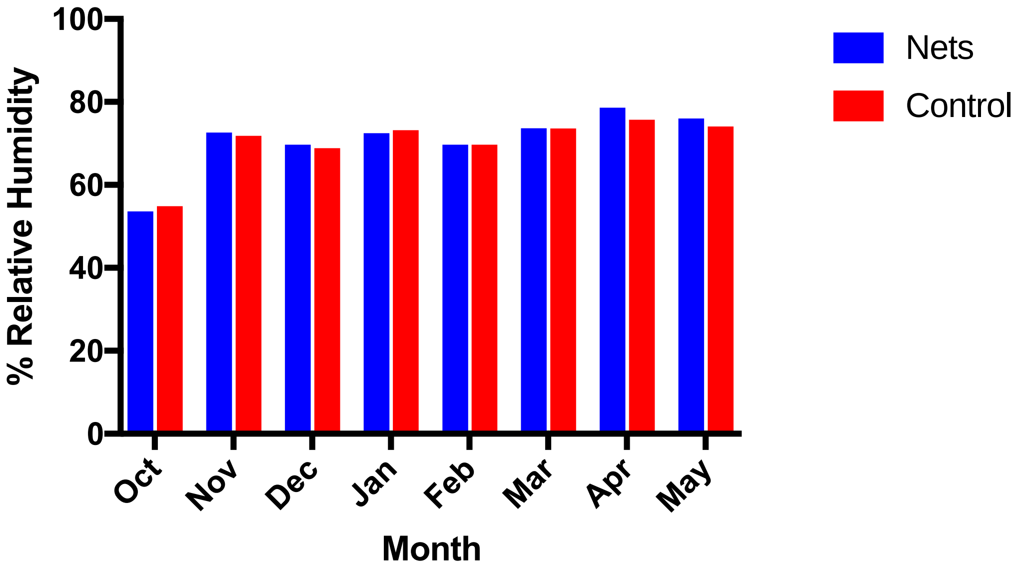

Fig. 9. Bar graph illustrating the effect of shade net on average relative humidity measured under the white shade nets and outside the nets, from October 2017 until May 2018, at Excelsior Farm, South Africa. Values are averages from readings taken every 30 minutes

Table 1. Summary of phenological dates for 'Larry Ann' and 'Midnight Gold' for the season of 2016/2017.

Phenological stage	'Larry Ann'	'Midnight Gold'
Full bloom	22 Sept 2016	07 Sep 2016
Harvest	13 Feb 2017	11 Jan 2017

Table 2. Summary of phenological stages for 'Larry Ann' and 'Midnight Gold' for the season of 2017/2018.

Phenological stage	'Larry Ann'	'Midnight Gold'
Full bloom	01 Oct 2017	17 Sep 2017
Harvest	19 Feb 2018	15 Jan 2018

Table 3. Effect of shade net on yield of 'Larry Ann' plums at Excelsior farm, South Africa, for the season 2016/2017.

Treatment	Yield efficiency ($kg.cm^{-2}$)	Average yield per tree (kg)
Control	0.48 a	20.42 ns
Under nets	0.42 b	20.65
Significance level	*0.0291*	*0.7864*
LSD 5%	*0.06*	-

Table 4. Effect of shade net on 'Larry Ann' fruit size, from Excelsior Farm, South Africa, for the season 2016/2017.

Treatment	Average fruit mass (g)	Average fruit diameter (mm)	Average fruit length (mm)
Control	116.44 a	62.15 a	53.03 a
Under nets	101.79 b	59.15 b	50.93 b
Significance level	*<0.0001*	*<0.0001*	*<0.0001*
LSD 5%	*3.91*	*0.79*	*0.70*

Table 5. Effect of shade net on firmness of ‘Larry Ann’ plums, from Excelsior Farm, South Africa, for the season 2016/2017.

Treatment	Firmness at harvest (N)	Firmness after 6 weeks storage at -0.5 °C (N)	Firmness after 1-week shelf-life at 10 °C (N)
Control	76.50 ns	55.11 ns	40.99 ns
Under nets	73.90	50.79	39.78
Significance level	*1.1604*	*0.2926*	*0.4488*
LSD 5%	-	-	-

Table 6. Effect of shade net on the average fruit maturity and peel color of ‘Larry Ann’ plums at harvest from Excelsior Farm, South Africa, for the season 2016/2017.

Treatment	TSS (ºBrix)	TA (%)	Color (Chroma)	Color (Hueº)	Color (Lightness)
Control	13.88 ns	2.01 ns	19.84 ns	23.80 ns	31.45 b
Under nets	14.57	2.05	20.25	24.63	32.66 a
Significance level	*0.0814*	*0.2794*	*0.1151*	*0.7459*	*<0.0001*
LSD 5%	-	-	-	-	*0.36*

Table 7. Effect of shade net on the average fruit maturity and peel color of ‘Larry Ann’ plums 6 weeks cold storage at -0.5°C, from Excelsior Farm, South Africa, for the season 2016/2017.

Treatment	TSS (ºBrix)	TA (%)	Color (Chroma)	Color (Hueº)	Color (Lightness)
Control	14.54 ns	1.22 ns	20.82 a	10.17 ns	32.80 b
Under nets	14.28	1.16	18.56 b	8.01	35.70 a
Significance level	*0.4070*	*0.0235*	*<0.0001*	*0.1607*	*<0.0001*
LSD 5%	-	-	*0.90*	-	*0.51*

Table 8. Effect of shade net on the average fruit maturity and peel color of 'Larry Ann' plums after 6 weeks cold storage and 1 week shelf-life at 10 °C, from Excelsior Farm, South Africa, for the season 2016/2017.

Treatment	TSS (ºBrix)	TA (%)	Color (Chroma)	Color (Hueº)	Color (Lightness)
Control	14.21 ns	3.47 a	16.46 a	1.87 ns	30.53 b
Under nets	14.14	3.44 b	13.62 b	1.58	32.99 a
Significance level	*0.8083*	*0.0396*	*<0.0001*	*0.8256*	*<0.0001*
LSD 5%	-	*0.03*	*0.41*	-	*0.43*

Table 9. Effect of shade net on average percentage physical damage of 'Larry Ann' plums from Excelsior Farm, South Africa, for the season 2016/2017.

Treatment	Sunburn (%)	Average sunburn score	Wind damage (%)	Average wind damage score
Control	0.9 ns	0.95 ns	22.40 a	2.69 ns
Under nets	0.5	0.79	16.17 b	2.56
Significance level	*0.1703*	*0.6445*	*0.0117*	*0.5590*
LSD 5%	-	-	*4.79*	-

**Sunburn score ranged from 0 to 5, where 0 represents no sunburn and 5 represents severe sunburn with necrosis. Wind damage score ranged from 0 to 8, with 8 being the most severe.*

Table 10. Effect of shade net on the percentage of postharvest disorders in 'Larry Ann' plums measured after 6 weeks cold storage at -0.5 °C, from Excelsior Farm, South Africa, for the season 2016/2017.

Treatment	Internal browning (%)	Gel breakdown (%)	Aerated tissue (%)	Shrivel (%)	Decay (%)
Control	1.0 ns	2.4 ns	1.4 ns	0.6 ns	7.2 a
Under nets	0.8	1.0	0.8	0	2.8 b
Significance level	*0.7947*	*0.1558*	*0.4313*	*0.1769*	*0.0069*
LSD 5%	-	-	-	-	*1.51*

Table 11. Effect of shade net on the percentage postharvest disorders in 'Larry Ann' plums after 6 weeks cold storage and 1 week shelf-life at 10 °C, from Excelsior Farm, South Africa, for the season 2016/2017.

Treatment	Internal browning (%)	Gel breakdown (%)	Aerated tissue (%)	Shrivel (%)	Decay (%)
Control	11.80 a	31.80 a	0.40 ns	0.0	2.40 ns
Under nets	29.00 b	9.10 b	1.00	0.0	4.00
Sign. level	*0.0131*	*0.0432*	*0.5843*	-	*0.4381*
LSD 5%	*6.57*	*6.57*	-	-	-

Table 12. Effect of shade nets on yield of 'Larry Ann' plums at Excelsior Farm, South Africa, for the season 2017/2018.

Treatment	Yield efficiency (kg·cm^{-2})	Average yield per tree (kg)
Control	0.14 ns	10.07 a
Under nets	0.13	7.87 b
Significance level	*0.7708*	*0.0142*
LSD 5%	-	*1.70*

Table 13. Effect of shade net on the average 'Larry Ann' fruit size, from Excelsior Farm, South Africa, for the season 2017/2018.

Treatment	Average fruit mass (g)	Average fruit diameter (mm)	Average fruit length (mm)
Control	136.24 ns	66.14 ns	63.16 ns
Under nets	130.90	65.96	53.95
Significance level	*0.0695*	*0.6241*	*0.0672*
LSD 5%	-	-	-

Table 14. Effect of shade net on the firmness of 'Larry Ann' plums, from Excelsior Farm, South Africa, for the season 2017/2018.

Treatment	Firmness at harvest (N)	Firmness after 6 weeks storage at -0.5°C (N)	Firmness after 1-week shelf-life at 10°C (N)
Control	91.88 a	75.76 a	11.82 ns
Under nets	86.17 b	67.0 b	10.61
Significance level	*<0.0001*	*0.0022*	*0.0925*
LSD 5%	*2.1729*	*3.9706*	-

Table 15. Effect of shade net on the average fruit maturity and peel color of 'Larry Ann' plums at harvest from Excelsior Farm, South Africa, for the season 2017/2018.

Treatment	TSS (ºBrix)	TA (%)	Color (Chroma)	Color (Hueº)	Color (Lightness)
Control	17.51 a	1.95 a	21.83 ns	23.80 ns	39.61 a
Under nets	16.47 b	1.90 b	21.54	24.63	36.33 b
Significance level	*<0.0001*	*0.0194*	*0.4010*	*0.7459*	*<0.0001*
LSD 5%	*0.38*	*0.05*	-	-	*0.89*

Table 16. Effect of shade net on the average fruit maturity and peel color of ‘Larry Ann’ plums after 6 weeks cold storage at -0.5 °C, from Excelsior Farm, South Africa, for the season 2017/2018.

Treatment	TSS (ºBrix)		TA (%)		Color (Chroma)		Color (Hueº)		Color (Lightness)	
Control	17.31	ns	1.39	ns	22.09	ns	14.46	ns	35.11	b
Under nets	16.36		1.36		21.34		14.10		37.10	a
Significance level	*0.2595*		*0.1774*		*0.3234*		*0.8354*		*0.0015*	
LSD 5%	-		-		-		-		*1.12*	

Table 17. Effect of shade net on the average fruit maturity and peel color of ‘Larry Ann’ plums after 6 weeks cold storage and 1 week shelf-life at 10 °C, from Excelsior Farm, South Africa, for the season 2017/2018.

Treatment	TSS (ºBrix)		TA (%)	Color (Chroma)		Color (Hueº)		Color (Lightness)	
Control	17.84	ns	**NA*	8.07	ns	2.45	ns	29.70	a
Under nets	17.38		-	7.71		358.66		30.72	b
Significance level	*0.1188*		-	*0.1516*		*0.0819*		*0.0497*	
LSD 5%	-		-	-		-		*1.01*	

**NA: juicing of overripe fruit produced a foam, which could not be titrated.*

Table 18. Effect of shade net on the average percentage physical damage of 'Larry Ann' plums from Excelsior Farm, South Africa, for the season 2017/2018.

Treatment	Sunburn (%)	Average sunburn score	Wind damage (%)	Average wind damage score
Control	1.4 a	1.17 a	1.87 a	1.5 a
Under nets	0.07 b	0.07 b	0.5 b	0.23 b
Significance level	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
LSD 5%	*0.39*	*0.33*	*0.60*	*0.44*

**Sunburn score ranged from 0 to 5, where 0 represents no sunburn and 5 represents severe sunburn with necrosis. Wind damage score ranged from 0 to 8, with 8 being the most severe.*

Table 19. Effect of shade net on the average percentage postharvest disorders of 'Larry Ann' plums after 6 weeks cold storage and 1 week shelf-life at 10 °C, from Excelsior Farm, South Africa, for the season 2017/2018.

Treatment	Internal browning (%)	Gel breakdown (%)	Aerated tissue (%)	Shrivel (%)	Decay (%)
Control	0	1.20 a	0	0	1.80 ns
Under nets	0	0.50 b	0	0	1.80
Significance level	-	*0.0150*	-	-	*1.000*
LSD 5%	-	*0.55*	-	-	-

Table 20. Effect of shade net on the yield of 'Midnight Gold' plums at Excelsior farm, South Africa, for the season 2016/2017.

Treatment	Yield efficiency (kg·cm^{-2})	Average yield per tree (kg)
Control	0.62 ns	24.11 ns
Under nets	0.57	23.95
Significance level	*0.2645*	*0.9125*
LSD 5%	-	-

Table 21. Effect of shade net on the average fruit size of ‘Midnight Gold’ plums, from Excelsior Farm, South Africa, for the season 2016/2017.

Treatment	Average fruit mass (g)	Average fruit diameter (mm)	Average fruit length (mm)
Control	98.47 ns	62.71 ns	44.65 ns
Under nets	97.79	61.67	44.40
Significance level	*0.5223*	*0.3289*	*0.1604*
LSD 5%	-	-	-

Table 22. Effect of shade net on the firmness of ‘Midnight Gold’ plums, from Excelsior Farm, South Africa, for the season 2016/2017.

Treatment	Firmness at harvest (N)	Firmness after 6 weeks storage at -0.5 °C (N)	Firmness after 1-week shelf-life at 10 °C (N)
Control	69.63 ns	53.54 ns	46.10 ns
Under nets	68.70	51.41	45.27
Significance level	*0.5255*	*0.1335*	*0.6528*
LSD 5%	-	-	-

Table 23. Effect of shade net on the average fruit maturity and skin color of ‘Midnight Gold’ plums at harvest from Excelsior Farm, South Africa, for the season 2016/2017.

Treatment	TSS (ºBrix)	TA (%)	Color (Chroma)	Color (Hueº)	Color (Lightness)
Control	12.11 a	1.49 b	11.10 a	17.72 a	28.09 a
Under nets	10.95 b	1.60 a	9.55 b	13.28 b	26.93 b
Significance level	*0.0015*	*<0.0001*	*<0.0001*	*0.0008*	*<0.0001*
LSD 5%	*0.65*	*0.05*	*0.39*	*2.3059*	*1.96*

Table 24. Effect of shade net on the average fruit maturity and peel color of ‘Midnight Gold’ plums after 6 weeks cold storage at -0.5 °C, from Excelsior Farm, South Africa, for the season 2016/2017.

Treatment	TSS (ºBrix)	TA (%)	Color (Chroma)	Color (Hueº)	Color (Lightness)
Control	13.22 a	1.16 ns	10.08 b	12.97 b	27.56 b
Under nets	11.88 b	1.16	12.97 a	14.51 a	27.99 a
Significance level	*0.0002*	*0.9233*	*<0.0001*	*0.0214*	*<0.0001*
LSD 5%	*0.59*	-	*0.48*	*1.28*	*0.21*

Table 25. Effect of shade net on the average fruit maturity and peel color of ‘Midnight Gold’ plums after 6 weeks cold storage and 1 week shelf-life at 10 °C, from Excelsior Farm, South Africa, for the season 2016/2017.

Treatment	TSS (ºBrix)	TA (%)	Color (Chroma)	Color (Hueº)	Color (Lightness)
Control	11.65 ns	1.08 ns	9.84 a	356.51 ns	27.15 ns
Under nets	12.07	1.11	9.12 b	358.36	27.25
Significance level	*0.3905*	*0.321*	*<0.0001*	*0.5378*	*0.1381*
LSD 5%	-	-	*0.19*	-	-

Table 26. Effect of shade net on the average percentage physical damage of ‘Midnight Gold’ plums from Excelsior Farm, South Africa, for the season 2016/2017.

Treatment	Sunburn (%)	Average sunburn score	Wind damage (%)	Average wind damage score
Control	0.43 ns	2.23 a	12.33 a	3.28 ns
Under nets	0.2	0.53 b	11.63 b	3.28
Significance level	*0.1118*	*<0.0001*	*0.0086*	*1.000*
LSD 5%	-	*0.42*	*0.51*	-

**Sunburn score ranged from 0 to 5, where 0 represents no sunburn and 5 represents severe sunburn with necrosis. Wind damage score ranged from 0 to 8, with 8 being the most severe.*

Table 27. Effect of shade net on the average percentage postharvest disorders of 'Midnight Gold' plums after 6 weeks cold storage at -0.5 °C, from Excelsior Farm, South Africa, for the season 2016/2017.

Treatment	Internal browning (%)	Gel breakdown (%)	Aerated tissue (%)	Shrivel (%)	Decay (%)
Control	0.0 ns	0.0 ns	2.00 ns	0	0
Under nets	0.4	0.8	0.00	0	0
Significance level	*0.1510*	*0.1250*	*0.5724*	-	-
LSD 5%	-	-	-	-	-

Table 28. Effect of shade net on the average percentage postharvest disorders of 'Midnight Gold' plums after 6 weeks cold storage and 1 week shelf-life at 10 °C, from Excelsior Farm, South Africa, for the season 2016/2017.

Treatment	Internal browning (%)	Gel breakdown (%)	Aerated tissue (%)	Shrivel (%)	Decay (%)
Control	0 a	0 a	1.60 ns	0	0.80 ns
Under nets	1.60 b	1.0 b	4.40	0	0.80
Sign. level	*0.0131*	*0.0382*	*0.1226*	-	*1.0*
LSD 5%	*0.61*	*0.47*	*1.82*	-	-

Table 29. Effect of shade nets on yield of 'Midnight Gold' plums at Excelsior Farm, South Africa, for the season 2017/2018.

Treatment	Yield efficiency ($kg \cdot cm^{-2}$)	Average yield per tree (kg)
Control	0.42 a	22.07 a
Under nets	0.27 b	15.95 b
Significance level	*0.0003*	*0.0020*
LSD 5%	*0.07*	*3.56*

Table 30. Effect of shade net on the average fruit size of ‘Midnight Gold’, from Excelsior Farm, South Africa, for the season 2017/2018.

Treatment	Average fruit mass (g)	Average fruit diameter (mm)	Average fruit length (mm)
Control	94.88 a	61.28 a	43.46 ns
Under nets	90.61 b	60.47 b	43.17
Significance level	*0.0003*	*0.0085*	*0.1750*
LSD 5%	*2.20*	*0.59*	-

Table 31. Effect of shade net on the firmness of ‘Midnight Gold’ plums, from Excelsior Farm, South Africa, for the season 2017/2018.

Treatment	Firmness at harvest (N)	Firmness after 6 weeks storage at -0.5 °C (N)	Firmness after 1-week shelf-life at 10 °C (N)
Control	69.06 a	62.37 a	10.77 a
Under nets	57.30 b	51.37 b	7.80 b
Significance level	*<0.0001*	*0.0002*	*0.0002*
LSD 5%	*4.1054*	*5.0086*	*1.3121*

Table 32. Effect of shade net on the average fruit maturity and peel color of ‘Midnight Gold’ plums at harvest from Excelsior Farm, South Africa, for the season 2017/2018.

Treatment	TSS (%)	TA (%)	Color (Chroma)	Color (Hue°)	Color (Lightness)
Control	*NA	1.58 a	10.35 a	357.45 ns	28.81 a
Under nets		1.47 b	9.42 b	356.54	27.47 b
Significance level	-	*<0.0001*	*<0.0001*	*0.6937*	*<0.0001*
LSD 5%	-	*0.05*	*0.40*	-	*0.34*

**missing data*

Table 33. Effect of shade net on the average fruit maturity and peel color of ‘Midnight Gold’ plums after 6 weeks cold storage at -0.5 °C, from Excelsior Farm, South Africa, for the season 2017/2018.

Treatment	TSS (%)		TA (%)		Color (Chroma)		Color (Hue°)		Color (Lightness)	
Control	14.17	a	1.17	a	12.24	a	357.45	ns	28.62	a
Under nets	13.33	b	1.09	b	10.03	b	356.54		26.69	b
Significance level	*0.0244*		*0.0068*		*<0.0001*		*0.6937*		*<0.0001*	
LSD 5%	*0.72*		*0.05*		*0.46*		-		*0.29*	

Table 34. Effect of shade net on the average fruit maturity and peel color of ‘Midnight Gold’ plums after 6 weeks cold storage and 1 week shelf-life at 10 °C, from Excelsior Farm, South Africa, for the season 2017/2018.

Treatment	TSS (%)		TA (%)	Color (Chroma)		Color (Hue°)		Color (Lightness)	
Control	14.51	a	**NA*	6.03	a	330.48	ns	25.66	a
Under nets	13.68	b		4.66	b	332.50		25.24	b
Significance level	*0.0462*		-	*<0.0001*		*0.3381*		*0.0061*	
LSD 5%	*0.81*		-	*0.19*		-		*0.30*	

**NA: Fruit were overripe and unable to be juiced for pH and TA analysis*

Table 35. Effect of shade net on the verage percentage physical damage of ‘Midnight Gold’ plums per carton of 50 fruit, from Excelsior Farm, South Africa, for the season 2017/2018.

Treatment	Sunburn (%)	Average sunburn score	Wind damage (%)	Average wind damage score
Control	1.57 ns	0.64 ns	38.37 a	1.64 a
Under nets	0.70	0.52	18.57 b	1.44 b
Significance level	*0.0504*	*0.4931*	*<0.0001*	*0.0232*
LSD 5%	-	-	*3.88*	*0.17*

Table 36. Effect of shade net on the post-harvest fruit quality of ‘Midnight Gold’ plums after 6 weeks cold storage at -0.5 °C, from Excelsior Farm, South Africa, for the season 2017/2018.

Treatment	Broken stones	Gel breakdown (%)	Aerated tissue (%)	Shrivel (%)	Decay (%)
Control	0 -	0	2.0 a	0	0
Under nets	0	0	0.0 b	0	0
Significance level	-	-	*0.0336*	-	-
LSD 5%	-	-	*1.83*	-	-

Table 37. Effect of shade net on the post-harvest fruit quality of ‘Midnight Gold’ plums after 6 weeks cold storage and 1 week shelf-life at 10 °C, from Excelsior Farm, South Africa, for the season 2017/2018.

Treatment	Broken stones		Gel breakdown (%)	Aerated tissue (%)		Shrivel (%)	Decay (%)	
Control	0.5	ns	0	17.0	a	0	0.30	ns
Under nets	0		0	2.4	b	0	0	
Significance level	*0.1211*		-	*<0.0001*		-	*0.1769*	
LSD 5%	-		-	*5.79*		-	-	

Table 38. Visual observation of bee activity around 'African Delight' trees number 5 (15 m from hive) and 18 (40 m from hive) under shade nets and in full sun during different times of the morning on 30/08/2017, at Sandrivier, Western Cape, South Africa. Bees observed over 5 min. period.

Treatment	Time	Orchard number	No. bees exiting hive	No. of bees at tree 5	No. bees at tree 18	Temperature (ºC)	Relative Humidity (%)
Control	10:25	33.1	375	1	0	26	45
	11:10	32	139	0	0	21.5	54.5
Under nets	10:30	85	4	0	0	20.5	45
	11:00	83.1	108	0	0	25.5	42.5
	11:30	83.2	21	0	0	16.6	73.5

Table 39. Visual observations, counted during each time slot, of bee activity around 'African Delight' trees number 5 (15 m from hive) and 18 (40 m from hive) under shade nets and in full sun during different times of the morning on 01/09/2017, at Sandrivier, Western Cape, South Africa. Bees observed over 5 min. period.

Treatment	Time	Orchard number	No. bees exiting hive	No. of bees at tree 5	No. bees at tree 18	Temperature (ºC)	Relative Humidity (%)
Control	10:00	33.1	241	2	3	20	60.5
	10:35	32	93	1	2	24	43.0
	11:30	31.1	180	20	15	27	42.5
Under nets	10:00	85	108	12	9	20.5	58
	10:20	83.1	159	12	10	21.5	45
	10:50	83.2	340	9	4	22.0	44.5

PAPER 2: Efficacy of Plant Growth Retardants on Japanese Plum Trees under Shade Nets

Abstract. **Plumtree vigor should be maintained to ensure annual good yields of high-quality fruit. Tree vigor increases when trees are grown under shade nets and can be contained by using plant growth regulators (PGRs). Paclobutrazol (PBZ) (1-(4-chlorophenyl)-4,4-dimethyl-2-(1,2,3-triazole-1-yl)pentan-3-ol), uniconazole (UCZ) ((E)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-yl)pent-1-en-3-ol) and prohexadione-calcium (ProCa) (calcium;4-(1-oxidopropylidene)-3,5-dioxocyclohexane-1-carboxylate) are commonly used PGRs, with ProCa being the newer option that is more ecotoxicologically favorable than PBZ and UCZ. Two separate PGR trials were conducted over two seasons on two Japanese plum cultivars 'Larry Ann' and 'Midnight Gold' which received either a low or high concentration of soil-applied PBZ and UCZ, or a single (at petal drop (PD)) or double (at petal drop plus four weeks later) application of foliar-applied PGRs in the first season, and effects recorded over two seasons. The efficacy of PGRs on reducing vegetative growth was minimal overall; only slight reductions were seen after UCZ applications at bloom in 'Midnight Gold'. Fruit thinning requirements were reduced in 'Larry Ann' after the double foliar PBZ and UCZ treatment in the first season, while in 'Midnight Gold' foliar applications of ProCa reduced fruit set and thus thinning in the first season. The yields of both cultivars were heavier after foliar applications of ProCa in season one, with a shift towards larger fruit compared to the untreated controls. Following the double foliar PBZ applications in season one, the following seasons' yield of 'Larry Ann' increased, while in 'Midnight Gold' yield increased after the UCZ applications at bloom. Fruit mass and diameter was generally increased by all PGR treatments compared to the controls in the second season, and very little to no effect on the occurrences of broken stones were seen.**

Additional index words: Paclobutrazol, uniconazole, prohexadione-calcium, 'Larry Ann', 'Midnight Gold', *Prunus salicina* Lindl., protective nets.

Commercial plum growers are increasingly using shade nets to protect the crop from sunburn, heat and wind damage. Nets modify the underlying microclimate by reducing incident light, wind speed, and temperature fluctuations, while relative humidity (RH) is often increased (Kalcsits et al., 2017; Middleton and McWaters, 2002). This often results in increased vegetative vigor of trees growing under nets, especially when trees are grown on vigorous rootstocks (Amarante et al., 2011; Middleton and McWaters, 2002). Excessive shoot growth under nets is due to a decrease in overall tree stress, an increase in water use efficiency and thus photosynthesis, as well as lower fruit set and crop load (Amarante et al., 2011; Basile et al., 2014; Kalcsits et al., 2017; Solomakhin and Blanke, 2008). Dwarfing rootstocks are currently unavailable for Japanese plum cultivars (*Prunus salicina* Lindl.), thus tree vigor needs to be maintained each season by pruning or use of plant growth regulators (PGRs) to ensure good return yields (Lurie et al., 1997). Pruning and thinning requirements may differ under shade nets due to the reductions in yield (Paper 1) and increase in vegetative growth (Amarante et al., 2011; Basile et al., 2014; Middleton and McWaters, 2002). Excessive vegetative growth negatively affects reproductive development, thus influencing the yield and fruit quality (Aśin and Vilardell, 2006; Miller 2002; Minas et al., 2018).

Initially, daminozide was the primary active ingredient in PGRs used to control vegetative growth predominantly in apple, but it has been replaced by more ecotoxicologically safe chemicals, most of which inhibit gibberellin (GA) biosynthesis (Miller, 2002; Rademacher, 2000). Gibberellin biosynthesis inhibitors are extensively used to reduce shoot growth, thus controlling tree vigor and maintain the carbohydrate source-sink balance, and reduce manual pruning costs (Miller, 2002; Rademacher, 2000). Vegetative growth is dependent on various hormones, GA being one of the main cell elongation activators, thus GA inhibitors are used to reduce vegetative growth so that more carbohydrate reserves are available for reproductive growth (Raz et al., 2010).

The efficacy of PGRs under nets may differ from trees in full sunlight due to the mentioned differences in microclimate, and to our knowledge, little research has been conducted on the efficacy of PGRs under shade nets, particularly paclobutrazol (PBZ) (Cultar®; Syngenta Crop Protection), uniconazole (UCZ) (Sunny®; Sumitomo Chemical Co., Ltd.) and prohexadione-calcium (ProCa) (Regalis®; BASF). Middleton and McWaters (2002) reported the higher RH under nets increased leaf wetness periods, which resulted in increased chemical application efficacy on various fruit types by permitting a longer absorption period for the chemicals. The reduced wind speeds enabled more efficient spray applications and reduced drift (Middleton and McWaters, 2002) therefore reduced application rates are possible. Nets may therefore be both economically and ecologically beneficial to the grower and the environment. Plant growth regulators should be applied at the correct developmental stage and during suitable weather conditions for most effective results (Rademacher, 2015).

Lurie et al. (1997) reported an increase in fruit size and earlier peel color development in ‘Red Rosa’ plum over two growing seasons following soil application of PBZ and UCZ. The yield was not affected, and the larger fruit size was due to earlier fruit set thus allowing a longer growing period as well as suppression of vegetative shoot growth allowing partitioning of more assimilates to reproductive growth (Lurie et al., 1997). Olivier et al. (1990) reported the inhibition of shoot growth by PBZ was not the sole factor resulting in increased fruit size, but a combination of altered dry matter allocation in favor of flower buds, which resulted in stronger and earlier flowers and thus larger fruit when PBZ was applied to ‘Songold’ trees in the fall. Paclobutrazol and UCZ are used in pome and stone fruits in some countries as either a soil drench or foliar spray, but due to its high persistence in the environment, maximum residue levels on fruit are often exceeded as the active chemical does not fully degrade (Rademacher, 2004, 2015). Uniconazole is, however, used extensively for vegetative shoot reduction in many fruit trees, but recently it has been used to reduce fruit set in some stone fruit such as apricot and cherry trees (Raz et al., 2010; Stern et al., 2009). Japanese plum trees set large numbers of flowers and blossom thinning by hand is costly, therefore a combination of thinning methods such as mechanical and chemical are often used.

Aśin and Vilardell (2006) reported that PBZ (250 $mg \cdot L^{-1}$) reduced shoot growth in ‘Banquilla’ pears in Spain, but to a lesser extent than ProCa (175 $mg \cdot L^{-1}$) and the now-banned chlormequat chloride (CCC) (500 $mg \cdot L^{-1}$). Aśin and Vilardell (2006) also recommended that to obtain an effect similar to that of CCC, PBZ and ProCa should be combined, as the rate of shoot reduction is quicker with ProCa, but the overall inhibition of shoot growth and regrowth is greater with PBZ. Due to stricter chemical regulations worldwide, including the lowering of maximum residue levels allowed on fruit, CCC has been replaced with chemicals such as ProCa. Prohexadione-calcium was registered in the 2000s and found to be an effective GA biosynthesis inhibitor, with favorable toxicological and environmental characteristics (Rademacher et al., 2006). Miller (2002) found that ProCa effectively reduced current season shoot growth on ‘Mercier Redchief Delicious’ apple trees, without affecting fruit quality or yield in the season after treatments or the following season, but the cumulative yield was decreased over three years. On the contrary, the yield in ‘Fuji’ apple trees (Costa et al., 2004) and ‘Arbequina’ olives (Schneider et al., 2010) increased without affecting fruit size, following treatments with ProCa. Glozer (2010) reported a successful reduction in shoot growth of around ca. 23 to 35% in ‘French’ prune with early ProCa applications applied as either a repeated application of 125 $mg \cdot L^{-1}$ or a single application of 250 $mg \cdot L^{-1}$ during early shoot elongation. It was also noted that yields of ‘French’ prune were improved with the early single treatments at either the low (125 $mg \cdot L^{-1}$) or high (250 $mg \cdot L^{-1}$) concentrations of ProCa, and the later applications at the higher concentrations (250 $mg \cdot L^{-1}$) reduced fruit size (Glozer, 2010). Smit (2002) reported no significant effects on ‘Songold’ plum tree reproductive development with various ProCa foliar treatments, but did report a reduction in shoot growth, with the most efficient treatment consisting of two low rate sprays at 125 $mg \cdot L^{-1}$, compared to one high dose of 250 $mg \cdot L^{-1}$. In vigorous apple trees, a double application of ProCa at a low concentration was found to be more effective than a single application of high concentration (Miller, 2002).

Broken stones (BS) in Japanese plums occur when the radial growth rate of the fruit exceeds the endocarp's ability to withstand these pulling forces, therefore stones are pulled apart (Kritzinger et al., 2017). In Japanese plums, stones start to mature when endocarp lignification starts, and this occurs at the stylar-end first, which is also where most breakages are observed but is also cultivar dependent (Kritzinger et al., 2017). Kritzinger et al. (2017) found that stones broke close to the start of stone lignification and changes in endocarp density, which happened around 28 days after full bloom (dafb) in 'Laetitia' and 'Songold' plums.

The objective of this study was to determine under shade nets the efficacy of PBZ, UCZ, and ProCa applied as foliar treatments, and PBZ and UCZ as soil treatments, in reducing vegetative growth in Japanese plum trees, without reducing yield or fruit quality.

Materials and Methods

Plant material and site description. The trials were conducted at the netted site described in Paper 1.

Treatments and experimental design. Two sets of trials were conducted, one evaluating soil-applied PGRs and one evaluating foliar-applied PGRs. Seven treatments in a randomized complete block design were evaluated with 10 single tree replicates for both 'Larry Ann' and 'Midnight Gold'. The trial ran over two seasons, and the PGRs were applied in the first season only, but trees were monitored the second season to determine whether a carry-over effect occurred. Treatments are summarized in Table 1 for soil applications and Table 2 for foliar applications, while treatment dates and phenological stages are summarized in Table 3. ProCa was applied as Regalis® (BASF SA (Pty) Ltd., Midrand, South Africa), UCZ as Sunny® 50 SL (Philagro SA (Pty) Ltd, Pretoria, South Africa,) and PBZ as Cultar® (Syngenta (Pty) Ltd, Centurion, South Africa). Trees that received the soil-applied PGR treatments were irrigated for at least one hour the day before treatment application, each tree then received 2 L of the PGR solution, with 1 L applied with a watering can to each side at the base of the tree trunk covering ca.1 m^2 surface area in total. Foliar PGR treatments were applied early in the morning using motorized back-pack sprayers (STHIL, Pietermaritzburg, South Africa) at a rate of ca. 1000 L per ha. In the spring in the 2016/2017 season, 'Larry Ann' PGRs were sprayed when temperatures were ±11 ºC and RH ±87%, while for 'Midnight Gold' temperatures were ±9 ºC and

RH ±80%. In the fall, 'Larry Ann' PGRs were sprayed when temperatures were ±11 ºC and RH ±85%, while for 'Midnight Gold' temperatures were ±8 ºC and RH ±80%. At least one tree and one row were left as a buffer between treatments.

Data collection. Hand thinning was performed according to commercial norms and all thinned fruitlets were counted and weighed after thinning. During the 2017/2018 season, 'Larry Ann' fruit set was extremely low, therefore fruitlet thinning was not performed. During commercial pruning of the trees in winter and summer, shoots were hand pruned and weighed per treatment to estimate the effect of the PGRs on vegetative shoot growth.

At the main commercial harvest date for each cultivar, the trees were strip picked, the total yield per tree was determined and a sample of 30 fruit from each experimental tree brought to the laboratory at the Department of Horticultural Science at Stellenbosch University. The mass, diameter, and length of fruit were determined using an electronic balance and digital caliper (Mitutoyo Corp., Kanagawa, Japan). The fruit were then cut open and checked for BS. Treatments applied after harvest in the 2016/2017 season would only have effects on the following season's fruit, therefore these results will not be discussed under the first season but rather in the second season. The occurrence of broken stones were minimal throughout the season, therefore results are not shown.

Statistical analysis. The data were analyzed using the General Linear Models (GLM) and procedure of SAS Enterprise Guide 7.1 (SAS Institute Inc., Cary, North Carolina, USA). A pair-wise *t* test was used to determine Fischer's Least Significant Difference (LSD) between the means when the F-statistic indicated a significance at $P<0.05$.

Results

'Larry Ann' 2016/2017 Season: Foliar PGR applications had a significant effect on the required fruitlet thinning as seen by the average number of hand thinned fruit in the first season. PBZ and UCZ, but not ProCa, applied once or twice (at petal drop (PD) and 4 weeks after PD) decreased the hand thinning requirement significantly compared to the control (Table 4). The PBZ and UCZ treatments did not differ from each other. Foliar treatments with ProCa (70 $mg \cdot L^{-1}$) resulted in significantly higher yields per tree compared to UCZ (50 $mg \cdot L^{-1}$) treatments but did not differ from the control or PBZ (250 $mg \cdot L^{-1}$) treatments, while the UCZ treatments did not differ from either the control or the PBZ treatments (Table 4).

All the foliar PGR applications resulted in significantly heavier 'Larry Ann' plums compared to the control, except the single ProCa treatment (Table 5). The single PBZ application at PD resulted in significantly heavier fruit compared to the double ProCa treatment and single UCZ treatment, while the remaining treatments did not differ from each other. The average diameter of fruit harvested from trees treated with the PBZ were significantly larger than fruit harvested from the control and trees treated with ProCa, while only the single PBZ application increased fruit size compared to the single UCZ application at PD. Fruit length followed a similar pattern with all treatments resulting in fruit being longer than the control fruit, except for fruit harvested from trees treated with a single application of ProCa at PD (Table 5). The foliar PGR applications did not affect the vegetative pruning requirements in the 2016/2017 season (Table 6).

The fruitlet thinning requirement of 'Larry Ann' was not affected by the soil PGR applications in the 2016/2017 season (Table 7). The yield of trees treated with the higher UCZ (50 $mg{\cdot}L^{-1}$) application after harvest was significantly higher than treatments with PBZ (250 $mg{\cdot}L^{-1}$) after harvest, UCZ (25 $mg{\cdot}L^{-1}$) at flowering and the untreated control. However, the yields of the remaining treatments did not differ from the control (Table 7). The 'Larry Ann' plums harvested from trees treated with the higher UCZ (50 $mg{\cdot}L^{-1}$) after harvest was significantly heavier than fruit from trees treated with the lower PBZ (125 $mg{\cdot}L^{-1}$) after harvest, both UCZ treatments and the control. Further, all the soil PGR treatments, except for the lower UCZ treatment at flowering, resulted in heavier fruit compared to the control (Table 8). The average diameter of fruit harvested from trees treated with the higher UCZ application after harvest was significantly larger than the control fruit, whilst the remaining treatments did not differ from one another or the control (Table 8). Fruit length was not affected by soil PGR treatments (Table 8). The occurrence of BS was less than 1% with no significant treatment differences (data not shown). The soil-applied PGRs did not affect the vegetative pruning requirements in the 2016/2017 season (Table 9).

'Midnight Gold' 2016/2017 Season: The double UCZ (50 $mg{\cdot}L^{-1}$) at PD, plus 4 weeks later resulted in significantly higher fruit thinning requirements compared to all other treatments, except for the treatment with PBZ (250 $mg{\cdot}L^{-1}$) at PD (Table 10). Fruitlet thinning requirements after the treatment with PBZ (50 $mg{\cdot}L^{-1}$) at PD did not differ significantly compared to the double PBZ or single UCZ treatments, but the thinning requirement was still significantly higher compared to that of the control and ProCa treatment (Table 10). The control had a higher yield compared to all treatments except from the ProCa (70 $mg{\cdot}L^{-1}$) applications. The single ProCa (70 $mg{\cdot}L^{-1}$) application resulted in a higher yield than the UCZ applications and the double PBZ application. Double UCZ applications resulted in a significantly lower yield compared to all other treatments (Table 10).

'Midnight Gold' fruit weight and length in the 2016/2017 season were increased significantly after applications of ProCa (70 mg·L^{-1}) at PD plus 4 weeks later compared to all treatments except from the single ProCa application at PD (Table 11). The remaining treatments showed no significant differences in fruit weight compared to the control but PBZ and UCZ decreased the fruit length compared to the control. No significant effects were seen on fruit diameter (Table 11). Broken stone incidence varied between 0 and 1.4% (data not shown). The double PBZ treatment lead to a significantly higher percentage of BS compared to the control and remaining ProCa and PBZ treatments, but did not differ from either UCZ treatment (data not shown). The foliar PGR applications did not affect the vegetative pruning requirements of 'Midnight Gold' trees in the 2016/2017 season (Table 12).

Soil applications of the lower PBZ (125 mg·L^{-1}) treatment applied after harvest resulted in a higher fruitlet thinning requirement compared to the higher PBZ (250 mg·L^{-1}) application applied after harvest, and the lower UCZ (125 mg·L^{-1}) application at flowering, but did not differ significantly from the remaining treatments nor the control (Table 13). Yield per tree was not affected by any PGR soil application compared to the untreated control; however, the higher PBZ treatment after harvest reduced the yield compared to the higher UCZ treatment at bloom (Table 13).

The higher UCZ (50 mg·L^{-1}) treatment at flowering resulted in heavier fruit compared to both the PBZ, and higher UCZ treatment applied after harvest, but did not differ significantly from the control (Table 14). The treatment with the lower PBZ application after harvest also yielded lighter fruit compared to all treatments except for the higher rate of PBZ and UCZ applied after harvest (Table 14). The average fruit diameter followed a similar pattern to fruit weight where the higher UCZ application at flowering resulted in the largest fruit diameter compared to both the PBZ, and higher UCZ applications after harvest, but did not differ from the control. The lower PBZ application after harvest resulted in fruit with significantly smaller diameters compared to all other treatments (Table 14). Fruit length was not affected by the soil applications in the 2016/20127 season (Table 14).

The summer punning requirement was significantly reduced after soil UCZ application at bloom compared to the control, while the remaining treatments applied after harvest did not reduce summer pruning compared to the control (Table 15). The higher concentration of UCZ had a greater effect than application at the lower concentration. However, treatment with the lower UCZ application at bloom did not lower the summer pruning requirements compared to the lower PBZ application or the higher UCZ application after harvest (Table 15). The winter pruning requirement was significantly reduced by UCZ applications applied at flowering compared to the control and other treatments, except for the higher concentration of UCZ that did not differ from the lower PBZ concentration applied after harvest (Table 15).

'Larry Ann' 2017/2018 Season: No hand thinning was done on 'Larry Ann' trees during the second season. The double PBZ (250 mg·L^{-1}) treatment applied at PD plus 4 weeks later the previous season, increased yield significantly compared to all the other treatments, while the double UCZ treatment resulted in the lightest yield compared to all treatments except for the control (Table 16). The remaining treatments did not result in yield differences compared to the control (Table 16). All of the foliar PGRs applied in the 2016/2017 season, resulted in an increase of fruit weight and diameter in the 2017/2018 season compared to the control, but did not differ among each other (Table 17). Fruit length was not affected by any foliar treatment (Table 17). The percentage of fruit with BS was less than 1% (data not shown). No carry-over effects were seen in the vegetative pruning requirements in the 2017/2018 season (Table 18).

The soil PGR applications to 'Larry Ann' trees in the 2016/2017 season did not result in any significant differences in yield in the 2017/2018 season (Table 19). The average fruit mass was significantly larger in trees that received the higher PBZ (250 mg·L^{-1}) application after harvest compared to all other treatments (Table 20). The average fruit diameter was significantly larger after the higher application of PBZ (250 mg·L^{-1}) after harvest compared to the control and treatments with the lower rates of UCZ and PBZ at flowering, and the lower UCZ and PBZ application after harvest. The average fruit length was not affected. The percentage of fruit with BS at harvest ranged from 0.2 to 2.7% (data not shown). Lastly, the soil PGR treatments did not affect the vegetative pruning requirements of 'Larry Ann' trees in the second season (Table 21).

'Midnight Gold' 2017/2018 Season: After the foliar PGR treatments in the 2016/2017 season, the fruit thinning requirements nor the average yield of 'Midnight Gold' trees were affected the following season (Table 22). The average fruit mass, diameter, and length of 'Midnight Gold' plums were also not affected by any of the soil PGR treatments (Table 23). Lastly, there were also no effects on the vegetative pruning requirements in the 2017/2018 season (Table 24).

No fruit thinning was required in the soil-applied PGR trial in the second season. Trees that received the higher UCZ (50 mg·L^{-1}) at flowering in the 2016/2017 season had significantly higher yield than all other treatments (Table 25). All of the trees receiving soil applied PGRs yielded heavier fruit compared to the control, while between-treatment differences showed that only the higher UCZ application after harvest resulted in heavier fruit compared to the lower UCZ (25 $mg{\cdot}L^{-1}$) application at flowering (Table 26). Furthermore, all soil-applied PGRs the previous season resulted in fruit having a significantly larger diameter than control fruit, whilst no differences were seen between the treatments. Fruit length was also significantly larger in all treatments, except for the lower UCZ (25 $mg{\cdot}L^{-1}$) treatment applied at flowering, compared to the control (Table 26). The percentage of BS ranged from 0.1 to 1.1% (data not shown).

A significantly lower summer pruning requirement was found following both the high and low UCZ applications applied at flowering, as well as the lower PBZ (125 $mg{\cdot}L^{-1}$) application applied after harvest compared to the control. The summer pruning requirements following the treatments with both UCZ concentrations and the higher PBZ concentration applied after harvest did not differ from the control (Table 27). No significant differences were found in the winter pruning requirements (Table 27).

Discussion

The use of shade nets is popular among fruit growers as a means to protect the fruit from harsh environmental conditions. However, changes in tree growth and fruit development occur, with an increase in vegetative growth and a decrease in yield being the most common trends under nets (Amarante et al, 2011; Kalcsits et al., 2017; Middleton and McWaters, 2002; Solomakhin and Blanke, 2008). Our trials aimed to reduce vegetative growth under nets without compromising yield and fruit quality.

Vegetative pruning requirement. The application of the foliar PGRs, UCZ and PBZ had little to no effect on the vegetative pruning requirements of both ‘Larry Ann’ and ‘Midnight Gold’ trees in the first season, with little carry-over effects in the second season. Smit (2002) reported effective shoot growth reduction on ‘Songold’ plums with both 125 and 250 $mg{\cdot}L^{-1}$ ProCa as either a single or double foliar application, which was well below what was used (70 $mg{\cdot}L^{-1}$) with little effect. Smit (2002) also noted that a repeated application three weeks after the first, applied around stone hardening, was more effective than the single application alone, and that ProCa was more effective on apple trees compared to ‘Songold’ plum trees. A reduction in the weight of hand pruned shoots was observed with soil-applied UCZ; however, the concentrations we used might have been too low for vegetative growth control. The UCZ soil treatments applied at flowering in the previous season reduced the summer and winter pruning requirements of ‘Larry Ann’ the following season. In

'Midnight Gold' the previous season's treatments of both UCZ applications at flowering and the PBZ applications after harvest, reduced the summer and winter pruning requirements in the second season compared to the other PGR treatments, respectively. The weight differences of the pruned shoots between the treatments and the control were however very small and could be considered horticulturally or commercially insignificant. The small differences in pruning weights found could possibly be explained by the concentrations of the PGRs used in comparison to other authors who found significant shoot growth reductions. Our concentrations of ProCa were well above what other authors have used as previously mentioned, yet ProCa was the least effective in reducing vegetative growth in our trials. On the other hand, Raz et al. (2010) noted that effective concentrations of PGRs such as UCZ used to control vegetative growth are generally around 1000 to 3000 $mg{\cdot}l^{-1}$, which is much higher than our concentrations (25 and 50 $mg{\cdot}l^{-1}$), which could explain why we saw minimal significant effects in reducing pruning requirements. However, when comparing concentrations used to reduce fruit set, they did not differ far from literature (Lurie et al., 1997; Miller, 2000; Raz et al., 2010; Smit, 2002; Stern et al., 2009), yet the effects were less intense in our trials. Asín and Vilardell (2006) found that PBZ applications on 'Conference' pears applied after the vegetative growth flushes were less effective for controlling vegetative growth compared to earlier PBZ applications. Miller (2002) reported that when apple trees were treated with ProCa at varying concentrations (125 to 500 $mg{\cdot}l^{-1}$) to control vegetative growth, that timing of application was more important and the most effective period for vegetative control was within 10 days of petal fall compared to applications two to three weeks later (Miller, 2002). Numerous factors would influence the efficacy of PGRs on controlling vegetative growth and this would require further investigation.

Fruitlet hand-thinning requirement. In the first season of the 'Larry Ann' trials, both the double foliar applications of PBZ and UCZ, applied at PD and PD plus four weeks later, reduced fruit set and thus the hand thinning requirement, while the soil-applied PGRs were ineffective. In 'Midnight Gold' trees, both the single and double foliar-applied ProCa treatments were the most effective fruit thinner, but thinning requirements were similar to that of the controls. In the second season no thinning was required on 'Larry Ann', or in 'Midnight Gold' after the soil PGR treatments the previous season as fruit set was generally low. The thinning effect of GA biosynthesis inhibitors such as UCZ, PBZ, and ProCa are related to the inhibition of pollen tube growth which prevents successful fertilization of the flowers (Raz et al., 2010; Stern et al., 2009). The PGR treatments applied after harvest in the first season often resulted in significant fruit thinning effects in the current season compared to the control, but this would however not be a due to the treatments that were applied after harvest therefore they can be regarded as 'untreated' trees. Similar to the untreated controls, these trees would not be subjected to GA-biosynthesis inhibition, therefore vegetative growth continued as normal and possibly overpowered the reproductive strength causing fruitlets to drop regardless of the PGR treatments.

Yield and fruit quality. In the first season, foliar applications of ProCa on 'Larry Ann' trees resulted in higher yields compared to other PGR treatments, but yields were similar to the control. In 'Midnight Gold', foliar ProCa applications also increased yields compared to the other treatments, whilst PBZ and UCZ yielded less fruit than the control. All of the foliar PGRs treatments on 'Larry Ann' resulted in heavier fruit compared to the control, whilst the after harvest treatments with either PBZ or UCZ resulted in fruit with larger diameters. In 'Midnight Gold' foliar treatments with ProCa resulted in larger fruit. Smit (2002) found no significant effects on yield, fruit size or quality when 'Songold' plum trees were treated with either a single or double ProCa application but did see a reduction in vegetative growth. Olivier et al. (1990) reported that foliar-applied PBZ (500 $mg{\cdot}dm^{-3}$) caused an earlier opening of 'Songold' plum flowers which allowed for a longer growing season and resulted in larger fruit at commercial harvest time. Costa et al. (2004) noted that when ProCa was applied as a foliar treatment for two consecutive years on 'Fuji' apples, return bloom was always greater, and similar or slightly higher yields followed, while only higher concentrations (250 $ml{\cdot}L^{-1}$) decreased yields compared to lower concentrations.

The double PBZ foliar application resulted in heavier yields in the subsequent season in 'Larry Ann', while foliar PGRs did not affect the yield of 'Midnight Gold' trees in the subsequent season. Soil applications of PGRs did not affect 'Larry Ann' yields, whilst the soil treatment containing the higher UCZ concentration applied at bloom resulted in heavier yields in 'Midnight Gold' trees in the following season. All of the foliar-applied PGRs increased the fruit mass and diameter of 'Larry Ann' plums but did not affect 'Midnight Gold' plums. Soil treatments with PBZ on 'Larry Ann' increased fruit mass and diameter, whilst in 'Midnight Gold' all of the soil treatments increased fruit mass the following season. Lurie et al. (1997) reported that treatments with PBZ (500 and 1000 $mg{\cdot}L^{-1}$) and UCZ (100 and 200 $mg{\cdot}L^{-1}$) on 'Red Rosa' plums resulted in increased fruit size without affecting yield or fruit internal quality. Glozer (2010) reported effective shoot reduction by ProCa applied as a single application 7, 11 or 19 DAFB of 250 $mg{\cdot}L^{-1}$ with no effects on crop load, while applications any later caused reductions in fruit size.

Conclusions

The foliar PGR treatments were ineffective in reducing the vegetative pruning requirements of ‘Larry Ann’ and ‘Midnight Gold’ trees throughout both seasons, while soil-applied PGRs, specifically UCZ applied at bloom, resulted in a small decrease of the vegetative pruning requirements of ‘Midnight Gold’. Therefore, higher rates of these two PGRs are probably required, or as mentioned by Japanese plum grower in Stellenbosch, a 500 $mg \cdot L^{-1}$ application of PBZ applied in February, followed by a 250 $mg \cdot L^{-1}$ application in the following spring would be more effective in reducing vegetative growth (personal communication Petru Du Plessis). The reduction in fruit set observed following the spring foliar application of PBZ and UCZ in ‘Larry Ann’ was an interesting side-effect. Hand thinning alone is also costly and time-consuming, therefore a reduction in fruit set in plums is beneficial as hand thinning requirements are reduced.

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Table 1. Treatment specifications for trials done with paclobutrazol (PBZ) and uniconazole (UCZ) as soil applications on 'Larry Ann' and 'Midnight Gold' for both seasons, 2016/2017 and 2017/2018, at Excelsior Farm in the Western Cape, South Africa.

'Larry Ann' soil treatments and 'Midnight Gold' soil treatments*
Untreated control
UCZ (25 mg·L^{-1}) at flowering
UCZ (50 mg·L^{-1}) at flowering
UCZ (25 mg·L^{-1}) after harvest
UCZ (50 mg·L^{-1}) after harvest
PBZ (125 mg·L^{-1}) after harvest
PBZ (250 mg·L^{-1}) after harvest

**'Midnight Gold' received an extra dose of UCZ after harvest by mistake during the 2017/2018 season which could have affected the 2017/2018 season's summer pruning results.*

Table 2. Treatment specifications for trials done with paclobutrazol (PBZ), uniconazole (UCZ) and prohexadione-calcium (ProCa) as foliar applications on 'Larry Ann' and 'Midnight Gold' in 2016/2017, at Excelsior Farm in the Western Cape, South Africa.

'Larry Ann' and 'Midnight Gold' Foliar treatments
Untreated control
ProCa (70 mg·L^{-1}) + 6 ml/100 L water Dash® as wetting agent at petal drop (PD)
ProCa (70 mg·L^{-1}) + 6 ml/100 L water Dash® as wetting agent at PD, plus 4 weeks later
PBZ (250 mg·L^{-1}) + 100 ml/100 L water Villa 51® wetting agent at PD
PBZ (250 mg·L^{-1}) + 100 ml/100 L water Villa51® wetting agent at PD, plus 4 weeks later
UCZ (50 mg·L^{-1}) + 200 ml/100 L water UP 50® wetting agent at PD
UCZ (50 mg·L^{-1}) + 200 ml/100 L water UP 50® wetting agent at PD, plus 4 weeks later

Table 3. Important phenological and treatment dates on 'Larry Ann' and 'Midnight Gold' plum for seasons 2016/2017 and 2017/2018, at Excelsior Farm in the Western Cape, South Africa

Phenological and treatment dates	2016/2017		2017/2018	
	'Larry Ann'	'Midnight Gold'	'Larry Ann'	'Midnight Gold'
Full bloom	22-Sept-2016	7-Sep-2016	1-Oct-2017	17-Sep-2017
Harvest	6-Feb-2017	11-Jan-2017	19-Feb-2018	15-Jan-2018
Summer pruning	23-Nov-2016	23-Nov-2016	13-Dec-2017	6-Dec-2017
Winter pruning	15-Aug-2017	15-Aug-2017	25-Sep-2018	25-Sep-2018
Foliar treatment at petal drop (PD)	30-Sep-2016	9-Sep-2016	-	-
Soil treatment at flowering	30-Sep-2016	9-Sep-2016	-	-
Soil treatment after harvest	10-Feb-2017	14-Jan-02017	-	-
Fruitlet thinning	1-Nov-2016	21-Oct-2016	-	25-Oct-2017

Table 4. Effect of foliar applications of paclobutrazol (PBZ), uniconazole (UCZ) and prohexadione-calcium (ProCa) at different stages, on the set and yield of 'Larry Ann' plums for the 2016/2017 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Average number of thinned fruit	Average yield (kg)
Untreated control	511 a	18.6 ab
ProCa (70 mg·L^{-1}) at petal drop (PD)	514 a	20.2 a
ProCa (70 mg·L^{-1}) at PD, plus 4 weeks later	369 ab	20.3 a
PBZ (0.25 mg·L^{-1}) at PD	205 c	17.5 ab
PBZ (0.25 mg·L^{-1}) at PD, plus 4 weeks later	299 bc	17.2 ab
UCZ (50 mg·L^{-1}) at PD	331 bc	16.3 b
UCZ (50 mg·L^{-1}) at PD, plus 4 weeks later	264 bc	17.7 b
Significance level	*0.0010*	*0.0177*
LSD 5%	158.81	*3.5*

Table 5. Effect of foliar applications of paclobutrazol (PBZ), uniconazole (UCZ) and prohexadione-calcium (ProCa) at different stages on fruit size of ‘Larry Ann’ plum for the 2016/2017 season at Excelsior Farm in the Western Cape, South Africa.

Treatment	Average fruit weight (g)		Average fruit diameter (mm)		Average fruit length (mm)	
Untreated control	99.4	d	56.34	e	50.53	b
ProCa (70 mg·L^{-1}) at petal drop (PD)	99.9	d	56.54	de	50.57	b
ProCa (70 mg·L^{-1}) at PD, plus 4 weeks later	105.8	c	57.47	cd	51.58	a
PBZ (250 mg·L^{-1}) at PD	118.7	a	60.19	a	52.24	a
PBZ (250 mg·L^{-1}) at PD, plus 4 weeks later	113.7	ab	59.48	ab	51.57	a
UCZ (50 mg·L^{-1}) at PD	109.9	bc	58.48	bc	51.76	a
UCZ (50 mg·L^{-1}) at PD, plus 4 weeks later	113.6	ab	59.15	ab	51.93	a
Significance level	*0.0001*		*0.0001*		*0.0001*	
LSD 5%	*5.9*		*1.05*		*0.90*	

Table 6. Vegetative pruning requirements done by hand after foliar applications of paclobutrazol (PBZ), uniconazole (UCZ) and prohexadione-calcium (ProCa) on 'Larry Ann' plum trees for the 2016/2017 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Average weight of summer vegetative pruning (kg)		Average weight of winter vegetative pruning (kg)	
Untreated control	0.55	ns	3.22	ns
ProCa (70 mg·L^{-1}) at petal drop (PD)	0.59		3.95	
ProCa (70 mg·L^{-1}) at PD, plus 4 weeks later	0.56		2.95	
PBZ (250 mg·L^{-1}) at PD	0.60		4.06	
PBZ (250 mg·L^{-1}) at PD, plus 4 weeks later	0.61		3.62	
UCZ (50 mg·L^{-1}) at PD	0.69		3.34	
UCZ (50 mg·L^{-1}) at PD, plus 4 weeks later	0.73		4.72	
Significance level	*0.8900*		0.1103	
LSD 5%	-		-	

Table 7. Effect of soil applications of paclobutrazol (PBZ) and uniconazole (UCZ) at different stages, on the set and yield of 'Larry Ann' plums for the 2016/2017 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Average number of thinned fruit		Yield per tree (kg)	
Untreated control	431	ns	21.82	bc
UCZ (25 mg·L^{-1}) at flowering	273		20.01	c
UCZ (50 mg·L^{-1}) at flowering	344		23.87	ab
UCZ (25 mg·L^{-1}) after harvest	327		23.31	abc
UCZ (50 mg·L^{-1}) after harvest	385		25.95	a
PBZ (125 mg·L^{-1}) after harvest	402		22.89	abc
PBZ (250 mg·L^{-1}) after harvest	376		20.29	c
Significance level	*0.1210*		*0.0179*	
LSD 5%	-		*3.51*	

Table 8. Effect of soil applications of paclobutrazol (PBZ) and uniconazole (UCZ) at different stages, on fruit size of 'Larry Ann' plums for the 2016/2017 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Average fruit mass (g)		Average fruit diameter (mm)		Average fruit length (mm)	
Untreated control	99.37	d	57.26	b	50.43	ns
UCZ (25 mg·L^{-1}) at flowering	99.94	d	57.87	ab	51.12	
UCZ (50 mg·L^{-1}) at flowering	105.82	c	57.93	ab	47.24	
UCZ (25 mg·L^{-1}) after harvest	118.66	a	58.33	ab	51.32	
UCZ (50 mg·L^{-1}) after harvest	113.68	ab	58.81	a	51.72	
PBZ (125 mg·L^{-1}) after harvest	109.95	bc	58.33	ab	51.38	
PBZ (250 mg·L^{-1}) after harvest	113.57	ab	58.34	ab	51.21	
Significance level	*0.0001*		*0.0001*		*0.3729*	
LSD 5%	*5.87*		*1.33*		-	

Table 9. Vegetative pruning requirements done by hand after soil applications of paclobutrazol (PBZ) and uniconazole (UCZ) on 'Larry Ann' plum trees for the 2016/2017 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Average weight of summer vegetative pruning (kg)		Average weight of winter vegetative pruning (kg)	
Untreated control	0.50	ns	3.81	ns
UCZ (25 mg·L^{-1}) at flowering	0.48		2.75	
UCZ (50 mg·L^{-1}) at flowering	0.49		2.44	
UCZ (25 mg·L^{-1}) after harvest	0.56		3.30	
UCZ (50 mg·L^{-1}) after harvest	0.48		3.43	
PBZ (125 mg·L^{-1}) after harvest	0.50		3.30	
PBZ (250 mg·L^{-1}) after harvest	0.42		2.56	
Significance level	*0.8900*		0.1765	
LSD 5%	-		-	

Table 10. Effect of foliar applications of paclobutrazol (PBZ), uniconazole (UCZ) and prohexadione-calcium (ProCa) at different stages, on the set and yield of 'Midnight Gold' plums for the 2016/2017 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Average number of thinned fruit	Yield per tree (kg)
Untreated control	412 dc	24.46 a
ProCa (70 mg·L^{-1}) at petal drop (PD)	362 d	21.54 ab
ProCa (70 mg·L^{-1}) at PD, plus 4 weeks later	322 d	20.10 abc
PBZ (250 mg·L^{-1}) at PD	591 ab	19.81 bc
PBZ (250 mg·L^{-1}) at PD, plus 4 weeks later	520 bc	12.89 de
UCZ (50 mg·L^{-1}) at PD	534 bc	16.36 cd
UCZ (50 mg·L^{-1}) at PD, plus 4 weeks later	667 a	11.83 e
Significance level	*0.0001*	*0.0001*
LSD 5%	*126.61*	*4.46*

Table 11. Effect of foliar applications of paclobutrazol (PBZ), uniconazole (UCZ) and prohexadione-calcium (ProCa) at different stages on fruit size of ‘Midnight Gold’ plum for the 2016/2017 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Average fruit weight (g)		Average fruit diameter (mm)		Average fruit length (mm)	
Untreated control	93.57	bcd	57.81	ns	44.66	b
ProCa (70 mg·L^{-1}) at petal drop (PD)	97.68	ab	53.30		45.26	ab
ProCa (70 mg·L^{-1}) at PD, plus 4 weeks later	99.89	a	59.27		45.45	a
PBZ (250 mg·L^{-1}) at PD	93.78	bc	58.34		43.18	cd
PBZ (250 mg·L^{-1}) at PD, plus 4 weeks later	91.48	cd	57.98		42.99	d
UCZ (50 mg·L^{-1}) at PD	89.46	d	57.35		43.18	cd
UCZ (50 mg·L^{-1}) at PD, plus 4 weeks later	94.74	bc	58.30		43.83	c
Significance level	*0.0001*		*0.8499*		*0.0001*	
LSD 5%	*4.20*		-		*0.72*	

Table 12. Vegetative pruning requirements done by hand after foliar applications of paclobutrazol (PBZ), uniconazole (UCZ) and prohexadione-calcium (ProCa) on 'Midnight Gold' plum trees for the 2016/2017 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Average weight of summer vegetative pruning (kg)	Average weight of winter vegetative pruning (kg)
Untreated control	3.07 ns	3.53 ns
ProCa (70 mg·L^{-1}) at petal drop (PD)	4.99	3.63
ProCa (70 mg·L^{-1}) at PD, plus 4 weeks later	2.63	3.60
PBZ (250 mg·L^{-1}) at PD	2.81	3.30
PBZ (250 mg·L^{-1}) at PD, plus 4 weeks later	2.56	2.96
UCZ (50 mg·L^{-1}) at PD	2.83	3.37
UCZ (50 mg·L^{-1}) at PD, plus 4 weeks later	2.96	3.30
Significance level	*0.2048*	*0.7045*
LSD 5%	-	-

Table 13. Effect of soil applications of paclobutrazol (PBZ) and uniconazole (UCZ) at different stages, on the set and yield of 'Midnight Gold' plums for the 2016/2017 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Average number of thinned fruit	Yield per tree (kg)
Untreated control	447 ab	19.22 ab
UCZ (25 mg·L^{-1}) at flowering	337 b	19.20 ab
UCZ (50 mg·L^{-1}) at flowering	440 ab	21.81 a
UCZ (25 mg·L^{-1}) after harvest	450 ab	21.09 ab
UCZ (50 mg·L^{-1}) after harvest	438 ab	21.07 ab
PBZ (125 mg·L^{-1}) after harvest	563 a	19.13 ab
PBZ (250 mg·L^{-1}) after harvest	383 b	18.44 b
Significance level	*0.0281*	*0.0001*
LSD 5%	*153.43*	3.31

Table 14. Effect of soil applications of paclobutrazol (PBZ) and uniconazole (UCZ) at different stages, on fruit size of 'Midnight Gold' plum for the 2016/2017 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Average fruit weight (g)		Average fruit diameter (mm)		Average fruit length (mm)	
Untreated control	95.63	ab	58.44	ab	44.53	ns
UCZ (25 mg·L^{-1}) at flowering	96.52	ab	58.56	ab	44.74	
UCZ (50 mg·L^{-1}) at flowering	100.12	a	59.38	a	40.90	
UCZ (25 mg·L^{-1}) after harvest	95.43	ab	58.44	ab	44.47	
UCZ (50 mg·L^{-1}) after harvest	92.54	bc	57.65	b	43.99	
PBZ (125 mg·L^{-1}) after harvest	87.78	c	56.69	c	43.28	
PBZ (250 mg·L^{-1}) after harvest	93.57	b	57.94	b	43.94	
Significance level	*0.0001*		*0.0001*		*0.5597*	
LSD 5%	5.01		*1.08*		-	

Table 15. Vegetative pruning requirements done by hand after soil applications of paclobutrazol (PBZ) and uniconazole (UCZ) at different stages, on 'Midnight Gold' plum trees for the 2016/2017 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Average weight of summer vegetative pruning (kg)		Average weight of winter vegetative pruning (kg)	
Untreated control	2.98	a	4.16	a
UCZ (25 mg·L^{-1}) at flowering	2.31	b	2.19	d
UCZ (50 mg·L^{-1}) at flowering	2.16	c	2.45	dc
UCZ (25 mg·L^{-1}) after harvest	2.81	a	4.16	a
UCZ (50 mg·L^{-1}) after harvest	2.66	ab	4.07	a
PBZ (125 mg·L^{-1}) after harvest	2.56	abc	3.19	bc
PBZ (250 mg·L^{-1}) after harvest	2.94	a	3.93	ab
Significance level	*0.0022*		*0.0001*	
LSD 5%	*0.44*		*0.80*	

Table 16. Effect of foliar applications of paclobutrazol (PBZ), uniconazole (UCZ) and prohexadione-calcium (ProCa) at different stages, on the set and yield of 'Larry Ann' plums for the 2017/2018 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Yield per tree (kg)
Untreated control	4.90 bc
ProCa (70 mg·L^{-1}) at petal drop (PD)	5.01 b
ProCa (70 mg·L^{-1}) at PD, plus 4 weeks later	5.42 b
PBZ (250 mg·L^{-1}) at PD	5.88 b
PBZ (250 mg·L^{-1}) at PD, plus 4 weeks later	8.63 a
UCZ (50 mg·L^{-1}) at PD	5.46 b
UCZ (50 mg·L^{-1}) at PD, plus 4 weeks later	3.41 c
Significance level	*0.0003*
LSD 5%	*1.98*

Table 17. Effect of foliar applications of paclobutrazol (PBZ), uniconazole (UCZ) and prohexadione-calcium (ProCa) at different stages, on fruit size of 'Larry Ann' plum for the 2017/2018 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Average fruit weight (g)	Average fruit diameter (mm)	Average fruit length (mm)
Untreated control	134.33 b	62.59 b	55.22 ns
ProCa (70 mg·L^{-1}) at petal drop (PD)	143.80 a	64.30 a	55.82
ProCa (70 mg·L^{-1}) at PD, plus 4 weeks later	148.72 a	64.88 a	56.56
PBZ (250 mg·L^{-1}) at PD	144.16 a	64.14 a	56.09
PBZ (250 mg·L^{-1}) at PD, plus 4 weeks later	152.18 a	65.39 a	57.08
UCZ (50 mg·L^{-1}) at PD	151.28 a	65.26 a	56.53
UCZ (50 mg·L^{-1}) at PD, plus 4 weeks later	151.59 a	65.29 a	56.19
Significance level	*0.0009*	*0.0009*	*0.0934*
LSD 5%	*8.61*	*1.34*	-

Table 18. Vegetative pruning requirements done by hand after foliar applications of paclobutrazol (PBZ), uniconazole (UCZ) and prohexadione-calcium (ProCa) on 'Larry Ann' plum trees for the 2017/2018 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Average weight of summer vegetative pruning (kg)	Average weight of winter vegetative pruning (kg)
Untreated control	3.23 ns	0.73 ns
ProCa (70 mg·L^{-1}) at petal drop (PD)	3.95	0.92
ProCa (70 mg·L^{-1}) at PD, plus 4 weeks later	2.95	0.73
PBZ (250 mg·L^{-1}) at PD	4.06	0.60
PBZ (250 mg·L^{-1}) at PD, plus 4 weeks later	3.62	0.88
UCZ (50 mg·L^{-1}) at PD	3.34	0.83
UCZ (50 mg·L^{-1}) at PD, plus 4 weeks later	4.72	1.00
Significance level	*0.1103*	*0.4451*
LSD 5%	-	-

Table 19. Effect of soil applications of paclobutrazol (PBZ) and uniconazole (UCZ) at different stages, on the set and yield of 'Larry Ann' plums for the 2017/2018 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Yield per tree (kg)
Untreated control	5.26 ns
UCZ (25 mg·L^{-1}) at flowering	5.13
UCZ (50 mg·L^{-1}) at flowering	5.77
UCZ (25 mg·L^{-1}) after harvest	4.40
UCZ (50 mg·L^{-1}) after harvest	2.46
PBZ (125 mg·L^{-1}) after harvest	4.46
PBZ (250 mg·L^{-1}) after harvest	3.68
Significance level	*0.2725*
LSD 5%	-

Table 20. Effect of soil applications of paclobutrazol (PBZ) and uniconazole (UCZ) at different stages, on fruit size of 'Larry Ann' plum for the 2017/2018 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Average fruit weight (g)	Average fruit diameter (mm)	Average fruit length (mm)
Untreated control	129.01 b	61.69 b	54.81 ns
UCZ (25 mg·L^{-1}) at flowering	130.39 b	61.77 b	54.96
UCZ (50 mg·L^{-1}) at flowering	132.55 b	62.62 ab	55.35
UCZ (25 mg·L^{-1}) after harvest	128.87 b	61.84 b	54.42
UCZ (50 mg·L^{-1}) after harvest	131.96 b	62.34 ab	54.83
PBZ (125 mg·L^{-1}) after harvest	131.70 b	62.28 b	54.93
PBZ (250 mg·L^{-1}) after harvest	140.67 a	63.50 a	55.80
Significance level	*0.0156*	*0.0399*	*0.1992*
LSD 5%	*6.70*	*1.16*	-

Table 21. Vegetative pruning requirements done by hand after soil applications of paclobutrazol (PBZ) and uniconazole (UCZ) at different stages, 'Larry Ann' plum trees for the 2017/2018 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Average weight of summer vegetative pruning (kg)	Average weight of winter vegetative pruning (kg)
Untreated control	3.81 ns	0.78 ns
UCZ (25 mg·L^{-1}) at flowering	2.75	0.64
UCZ (50 mg·L^{-1}) at flowering	2.45	0.36
UCZ (25 mg·L^{-1}) after harvest	3.02	0.65
UCZ (50 mg·L^{-1}) after harvest	3.43	0.55
PBZ (125 mg·L^{-1}) after harvest	3.30	0.89
PBZ (250 mg·L^{-1}) after harvest	2.56	0.54
Significance level	*0.1765*	*0.3428*
LSD 5%	-	-

Table 22. Effect of foliar applications of paclobutrazol (PBZ), uniconazole (UCZ) and prohexadione-calcium (ProCa) at different stages, on the set and yield of 'Midnight Gold' plums for the 2017/2018 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Average number of thinned fruit	Yield per tree (kg)
Untreated control	44 ns	14.89 ns
ProCa (70 mg·L^{-1}) at petal drop (PD)	52	15.73
ProCa (70 mg·L^{-1}) at PD, plus 4 weeks later	50	21.10
PBZ (250 mg·L^{-1}) at PD	101	20.27
PBZ (250 mg·L^{-1}) at PD, plus 4 weeks later	46	14.84
UCZ (50 mg·L^{-1}) at PD	33	14.32
UCZ (50 mg·L^{-1}) at PD, plus 4 weeks later	85	18.17
Significance level	*0.0809*	*0.6399*
LSD 5%	-	-

Table 23. Effect of foliar applications of paclobutrazol (PBZ), uniconazole (UCZ) and prohexadione-calcium (ProCa) at different stages, on fruit size of 'Midnight Gold' plum for the 2017/2018 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Average fruit weight (g)	Average fruit diameter (mm)	Average fruit length (mm)
Untreated control	91.26 ns	57.27 ns	43.88 ns
ProCa (70 mg·L^{-1}) at petal drop (PD)	88.73	56.85	43.59
ProCa (70 mg·L^{-1}) at PD, plus 4 weeks later	90.29	56.91	43.96
PBZ (250 mg·L^{-1}) at PD	93.60	57.57	44.14
PBZ (250 mg·L^{-1}) at PD, plus 4 weeks later	91.85	57.48	43.94
UCZ (50 mg·L^{-1}) at PD	89.41	56.85	43.61
UCZ (50 mg·L^{-1}) at PD, plus 4 weeks later	88.03	56.53	43.24
Significance level	*0.6546*	*0.7029*	*0.6869*
LSD 5%	-	-	-

Table 24. Vegetative pruning requirements done by hand after foliar applications of paclobutrazol (PBZ), uniconazole (UCZ) and prohexadione-calcium (ProCa) on ‘Midnight Gold’ plum trees for the 2017/2018 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Average weight of summer vegetative pruning (kg)	Average weight of winter vegetative pruning (kg)
Untreated control	3.53 ns	2.59 ns
ProCa (70 mg·L^{-1}) at petal drop (PD)	3.63	3.03
ProCa (70 mg·L^{-1}) at PD, plus 4 weeks later	3.60	2.80
PBZ (250 mg·L^{-1}) at PD	3.30	3.30
PBZ (250 mg·L^{-1}) at PD, plus 4 weeks later	2.96	2.93
UCZ (50 mg·L^{-1}) at PD	3.37	2.74
UCZ (50 mg·L^{-1}) at PD, plus 4 weeks later	3.30	2.47
Significance level	*0.7045*	*0.3574*
LSD 5%	-	-

Table 25. Effect of soil applications of paclobutrazol (PBZ) and uniconazole (UCZ) at different stages, on the set and yield of ‘Midnight Gold’ plums for the 2017/2018 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Yield per tree (kg)
Untreated control	12.08 b
UCZ (25 mg·L^{-1}) at flowering	13.51 b
UCZ (50 mg·L^{-1}) at flowering	17.94 a
UCZ (25 mg·L^{-1}) after harvest	11.39 b
UCZ (50 mg·L^{-1}) after harvest	10.38 b
PBZ (125 mg·L^{-1}) after harvest	12.22 b
PBZ (250 mg·L^{-1}) after harvest	13.05 b
Significance level	*0.0007*
LSD 5%	*3.22*

Table 26. Effect of soil applications of paclobutrazol (PBZ) and uniconazole (UCZ) at different stages, on fruit size of 'Midnight Gold' plum for the 2017/2018 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Average fruit weight (g)	Average fruit diameter (mm)	Average fruit length (mm)
Untreated control	94.05 c	57.98 b	44.36 b
UCZ (25 $mg \cdot L^{-1}$) at flowering	101.59 b	59.93 a	44.64 b
UCZ (50 $mg \cdot L^{-1}$) at flowering	106.53 ab	61.05 a	45.93 a
UCZ (25 $mg \cdot L^{-1}$) after harvest	105.48 ab	60.24 a	45.96 a
UCZ (50 $mg \cdot L^{-1}$) after harvest	110.04 a	60.99 a	45.98 a
PBZ (125 $mg \cdot L^{-1}$) after harvest	106.71 ab	60.06 a	45.77 a
PBZ (250 $mg \cdot L^{-1}$) after harvest	107.88 ab	60.47 a	45.92 a
Significance level	*0.0001*	*0.0004*	*0.0021*
LSD 5%	*6.33*	*1.33*	*0.99*

Table 27. Vegetative pruning requirements done by hand after soil applications of paclobutrazol (PBZ) and uniconazole (UCZ) at different stages, on 'Midnight Gold' plum trees for the 2017/2018 season, at Excelsior Farm in the Western Cape, South Africa.

Treatment	Average weight of summer vegetative pruning (kg)	Average weight of winter vegetative pruning (kg)
Untreated control	4.16 a	4.76 ns
UCZ (25 $mg \cdot L^{-1}$) at flowering	2.20 d	4.38
UCZ (50 $mg \cdot L^{-1}$) at flowering	2.46 cd	4.61
UCZ (25 $mg \cdot L^{-1}$) after harvest	4.16 a	4.76
UCZ (50 $mg \cdot L^{-1}$) after harvest	4.07 a	5.08
PBZ (125 $mg \cdot L^{-1}$) after harvest	3.19 bc	4.46
PBZ (250 $mg \cdot L^{-1}$) after harvest	3.93 ab	4.28
Significance level	*0.0001*	0.4451
LSD 5%	*0.80*	-

PAPER 3: Research Questionnaire from Selected Japanese Plum Orchards under Nets in the Western Cape

Abstract. **Protective nets have gained popularity among fruit growers over the years as a means to protect trees from harsh environmental conditions and potentially increase the yield of high-quality fruit. We wanted to get an overview of the main reasons growers in the Western Cape installed nets over their Japanese plum orchards. Four Japanese plum growers were selected in different regions of the Western Cape Province of South Africa, whom each received a questionnaire about the structure of the nets, and the results that were obtained or expected to be achieved in their respective orchards. In addition, they were personally interviewed to discuss answers. The most popular reason for setting up a permanent flat net structure was protection against wind damage, while one grower constructed a retractable gabled structure for protection against hailstorms, which are common in that area. Sunburn damage was the second most popular reason for setting up nets, followed by expected improvements on fruit quality such as increased fruit size and yield. Only three of the growers had orchards already in fruit production when the questionnaire was answered, the 8-year-old orchard saw an increase in yield, the 3-year-old orchard experienced a slight decrease, and the third saw no big differences in yield as of yet under nets. Furthermore, the three growers commented that it took between 2 and 5 years to reach break-even on the investment. An increase in vegetative growth was observed by all growers, however, on younger trees, this was a positive response as trees filled their allotted space quicker. Overall, the response from the growers was positive and they recommend the use of shade nets as an integrated approach to improving fruit quality.**

Additional index words: protective nets, shade net, hail net, stone fruit, *Prunus salicina* Lindl., wind damage, sunburn, fruit quality, crop protection.

Protective nets may significantly increase the pack-out percentage of apple orchards without negatively impacting the total yield by decreasing and or eliminating physical damage to fruit from either pests or environmental hazards, improving peel color and increasing fruit size (Middleton and McWaters, 2000). Protective nets, made of various plastics, are widely used in agriculture as means of protection from hail, wind, and light snow, extreme heat, and high irradiance, as well as aiding in the reduction of water use in fruit orchards (Castellano et al., 2008). Hail and wind may cause physical damage to both the trees and fruit, while prolonged periods of extreme heat and high irradiance cause the physiological disorder known as sunburn leading to fruit peel discoloration and or necrosis (Dussi et al., 2005; Middleton and McWaters, 2002).

Protective nets are designed to reduce light and wind speed within the orchard and may be constructed as a complete closed structure with sides closed and extending to the ground, partially open, or open on the sides with only the top covered. Net threads are either woven or knitted at different densities, and may be various colors, the more common options being black, green and transparent (Blanke, 2014; Castellano et al., 2008). Photo-selective nets, which describe the various colors of nets that selectively screen out certain wavelengths of light, are used to alter the light spectrum to induce specific plant responses such as flowering, and mostly used in floriculture and production nurseries (Castellano et al., 2008; Stamps, 2009). The installation of net structures is a great financial cost, but the effects obtained may outweigh the initial high costs, thus protective nets are seen as a significant investment in optimizing orchard productivity (Middleton and McWaters, 2000).

Orchards under nets often experience a more favorable environment, thus both vegetative and reproductive growth is enhanced, which may include the increased growth of both beneficial cover crops and unwanted weeds between rows (Kalcsits et al., 2017; Middleton and McWaters, 2002), and possibly benefit the growth of beneficial cover crops. Under various colored nets, with increasing shading percentages, Middleton and McWaters (2002) reported 12 to 27% reductions in sunlight, an increase in relative humidity (RH) of up to 10 to 15%, up to 50% reduced wind speeds and 1 to 3 ºC reductions in daytime temperatures. These environment alterations may result in better water use efficiency of the trees as well as an increase in light scattering to all parts of the tree, and therefore increased vegetative growth and tree vigor under nets (Middleton and McWaters, 2000; 2002). However, some trees may experience a lower yield due to the decrease in carbohydrate supplies as a result of lower light levels under nets (Middleton and McWaters, 2002). Amarante et al. (2011) concluded from a study done on apples under white nets, that reduced light supply by 18.4% did not affect yield, but some fruit had reduced total soluble sugar concentrations, although the significant reduction in physical damage and physiological disorders in fruit harvested from under the nets outweighed any negative effects. Kalcsits et al. (2017) reported reduced soil temperatures under pearl and blue nets that reduced light by 20%, also increased RH up to 40% and reduced wind speed within an apple orchard compared to uncovered controls. As a result, fruit surface temperatures were reduced and thus sunburn damage and overall fruit and tree stresses were minimized (Kalcsits et al., 2017).

Net structures are designed according to the type of protection a grower needs, which is based on prevailing climatic conditions in the growing region. Areas that receive high solar radiation resulting in sunburn damage to fruit require, but are not limited to, flat net structures that may be permanently closed or retractable. Areas prone to hailstorms benefit form gabled or pergola structures where the troughs would have open gaps for hail to fall through to the ground between rows. Retractable nets are used in areas prone to snow as to prevent snow build up on the net structures which could result in collapsing of the nets. Nets are supported by structures made of wood and steel, and orchards may be fully enclosed or partially closed with the sides open (Blanke, 2014; Castellano et al., 2008).

This paper is a summary of the results of a questionnaire obtained by interviewing four growers in the Western Cape Province that make use of shade nets to protect their Japanese plum crop. The aim was therefore to obtain an overview of the current situation relating to the use of nets in Japanese plum orchards in the Western Cape, South Africa.

Materials and Methods

Selecting growers and data collection. We selected four plum growers from four different climatic areas. We aimed to select growers that made use of different net types and or production techniques that would otherwise be different from orchards not under nets. The growers were contacted, upon agreement to participate in the study they were each emailed a copy of the questionnaire, a confidentially form, and a waiver to use the information for this research project. In addition, the farms were visited, and the growers were interviewed in person. Each grower received the same questionnaire and answered as many questions as applicable to their selected cultivars and or blocks. The additional information obtained from the personal interviews were added to the final answers, as well as some photographs of the selected orchards to illustrate certain aspects. Growers that had a large number of Japanese plum cultivars were given the option to select at least two for answering questions specific to the cultivars and to give an overall impression of the orchard's productivity under the nets and any additional comments that were deemed significant.

The selected orchards were all in the Western Cape Province of South Africa and ranged from flat areas to valleys and or mountainous areas, all of which experienced strong seasonal wind, sunburn and or hail. Only three out of the four growers had established orchards already in fruit production before the nets were installed, while the remaining one installed nets over a new orchard had that not yet set fruit. A description of the four orchards are listed below, and images of the nets can be found in Fig.1 to 7.

A. The grower in Stellenbosch (33.88.69° S, 18.84.94° E) installed the nets in 2018 over various Japanese plum cultivars that were between four and six years old. The nets were installed after the harvest whilst trees were not in fruit production. The various cultivars were all budded on 'Maridon' rootstocks and consisted of 'Black Pearl', 'Angeleno', 'Fortune', 'Laetitia' and 'Songold'. Tree spacing was 4.0 x 1.5 m, and 15 hectares (ha) were covered by a permanent flat net structure. The top of the net was crystal clear in color and is specified to reduced UV by 20% and visible light by 6%, and all the sides were closed with a 40% green net connected to the ground at a 45° angle, and type of net used was knitted (Knittex, Multiknit). The soil of the orchard is plinthic type with 14% clay content, 70 cm deep and considered highly suitable for stone fruit.

B. The grower in the Overhex valley (33°64'99.797'' S, 19°53'81.901'' E) near Worcester constructed the nets in 2016 over a 1 ha section of equal blocks of 'Larry Ann' grafted onto 'Viking' rootstock and planted in 2013, and 'Midnight Gold' and 'August Yummy' budded on 'Marianna' rootstocks, and planted in 2014 (for more details on this block, see Paper 1). The net is a knitted (Knittex, Multiknit), 20% crystal white shade net, and constructed as a permanent flat structure with all sides open.

C. The grower in the Koo Valley (33˚42.169' S, 19˚52.937' E), situated outside the town of Montagu in the Klein Karoo, installed the nets in 2017 over 2 ha of 'Autumn Treat' plums trees on 'Marianna' rootstocks. The trees were planted in the same year the nets were installed and were not yet in production. The net structure was set up as a gabled, retractable structure with 20% woven black nets with the sides open. The nets are opened during the first week of May throughout winter and after pollination, then closed again at the end of October.

D. The grower in Wellington (33˚35'58.16" S, 18˚55'40.55 E) constructed the nets in 2016 over an 8-year-old orchard consisting of 17 different Japanese plum cultivars budded in on 'Marianna' or 'Kakamas' rootstocks. The nets were constructed as permanent flat structures over 43 ha. The structures are closed on all sides, and consists of a woven 20% white net used for all sides and the top. The orchard is on a heavy clay soil type.

Creating the questionnaire. The questionnaire was created based on four main aspects that we wanted to cover, most of which are discussed in the available literature on other fruit, but minimal information exists on Japanese plums grown under nets. Firstly, the geographical and structural aspects were included as questions about the growing region, orchard history and nets structure. The second section included questions on the physical properties of the nets. The third section included questions on the yield and fruit quality after the nets were installed. Lastly, the fourth section included questions on the changes in the environment under the nets. A copy of each answered questionnaire by the respective growers can be found in Appendix A.

For the sake of confidentiality, the participants will remain anonymous and therefore the answers provided are combinations of the responses of all four growers, with some points having references to a specific farm as listed from A to D. Growers were asked to sign a letter stating that the information they provided was as factually correct as possible (Appendix B), which also served as a proof that the information may be used for research purposes in this study.

Questionnaire Results and Interview Discussion

GENERAL QUESTIONS AND ANSWERS ABOUT THE FARM & NET SET UP

1. What was the most important reason(s) for putting up a net structure?

The most common reason noted by all of the growers was protection against harsh environmental conditions causing severe physical damage to fruit. For grower A, the main reason was protection against wind, followed by hail. For grower B it was protection against wind. For grower C it was protection against sunburn, followed by potential reductions in water usage, and lastly, hail protection. For grower D it was protection against sunburn and wind, followed by potential water usage reductions.

2. Please describe the orchard set up (location of the farm, cultivars, rootstock, vigor)

See Materials and Methods

3. When did you construct the netting structure? (year)

See Materials and Methods

4. How old was the orchard when establishing the net structure?

See Materials and Methods

5. How long did it take to break-even on the netting structure's costs?

The cost of putting up nets were recuperated within 2 and 5 years on farms B and D, respectively, that were already in fruit production, while on farm A the net structure was still being installed over parts of the orchard and farm C was not yet in fruit production. The plum trees under nets on farm C were planted the same year the nets were installed thus the grower was still expecting his first return on investment, while the installation of net structure on farm A was not yet completed, thus input costs cannot be calculated yet.

6. To what extent did you have to alter the general orchard practices due to the net structure, i.e. tree management/pruning, irrigation, fertilization, pollination?

More attention to summer pruning management was a common response among growers with pruning either needed to be done earlier or more often to control extra growth. Soil water retention after irrigation cycles lasted longer under the nets which led to less frequent irrigation. None of the growers noted any extreme changes in bee activity or nutrient fertilization practices. Younger trees filled their allotted space much quicker under nets, which is seen as a positive aspect when establishing new orchards.

QUESTIONS AND ANSWERS ABOUT NET STRUCTURE

1. How large is the area covered by the netting structure?

The most common area covered was between 1 and 2 hectares, over one block, while two farms covered 15 and 43 hectares under nets, respectively, which included the covering of roads.

2. What type of netting structure have you installed?

The most common structure was a permanent flat structure closed on all sides (Fig. 1, 2, and 3), while only two growers differed, where one structure had open ends and a flat top (Fig. 4 and 5), and another open ends with a retractable gabled structure (Fig. 6 and 7).

3. Is the structure retractable? If the net structure is retractable, when do you open and close the nets?

The one structure that was retractable, which was installed on Farm C, is opened during the first week of May and closed towards the end of October after pollination.

4. What color, type (woven/knitted) and shade percentage net have you used?

Net types that were used ranged between 20% woven nets either black (Farm D) or white/crystal white knitted nets (Farm A and C) or 20% UV and 6% shade white woven nets (Farm A) (remaining manufacturer information not given by growers).

5. How much space is left between the tops of the trees and the net?

Spaces left between nets and treetops were mostly between 1.2 and 1.5m, while one grower left a space of 2m between tree tops and net.

QUESTIONS AND ANSWERS ABOUT FRUIT YIELD AND TREE GROWTH UNDER NETS

1. Did you experience an increase or decrease in overall yield per cultivar? List different cultivars in the top column if there is more than one and tick appropriate boxes and indicate the approximate level of change in percentage.

Grower D reported an increase of 8 to 13% in yield in 'Ruby Star' and 'African Delight' plums which were planted in 2012. In the younger orchards on farm B 'August Yummy' decreased by about 20%, 'Midnight Gold' decreased by 5-10%, and 'Larry Ann' experienced no changes in yield. The grower from farm C had not yet set fruit, while grower A was still expecting the seasons' crop.

2. What effect did the nets have on return bloom for each cultivar?

None of the growers noted a major negative effect on return bloom apart from being a few days later or earlier, but nothing out of the ordinary. The newly planted trees under the retractable net had an extremely heavy bloom of flowers, but it was their first set therefore it was difficult to say if this was a result of the nets.

3. What changes did you see with regard to fruit size?

Grower A had not yet harvested fruit since the nets were installed but was expecting an increase in fruit size. Grower B saw a 20% decrease in 'August Yummy' and a 5% decrease in 'Midnight Gold' fruit size under the nets. The trees on farm C have not yet set their first crop. Grower D saw an increase in the size of 'Ruby Star' plums under nets, but a slight decrease in 'African Delight' fruit size.

4. Sunburn/heat damage and/or wind damage effects?

Grower A expected a 50% reduction in wind damage to the following seasons' yield, grower B saw a reduction in wind damage and sunburn, farm C had not yet set fruit, and grower D reported a reduction in sunburn, wind damage and heat damage to all cultivars.

5. What was the effect on harvest maturity?

The most common answer was no changes seen in fruit maturity under nets, except a slight advance in color on 'African Delight' plums from farm D.

6. Did you receive any feedback on post-harvest fruit quality?

Only two growers, B and D, received feedback from pack houses, and both reported no changes to post-harvest quality or physiological disorders in fruit harvested from under the nets.

7. Comments on pack-out percentages per cultivar?

Grower D reported an increase in class 1 fruit export by 13% in 'Ruby Star' and 8.4% in 'African Delight' plums under the nets, while grower B reported a positive increase in packout percentage of fruit from under nets.

8. Did you receive a better income and indicate percentage change?

Grower D said they received the same price per carton; however, they were able to pack out and or export between 8 and 13% more class 1 cartons of fruit per hectare from under the nets.

9. Did you experience an increase or decrease in pest damage, and by how much?

No significant changes were found in pest damage, except that one grower suspected fruit fly and false codling moth damage would be reduced under the completely enclosed net structures as trees would be enclosed under nets.

10. Did you experience an increase or decrease in disease damage, and by how much?

No significant differences were seen in disease damage.

11. Give a quick description of any major changes to tree growth?

Tree regrowth was found to be quicker after pruning, and as soon as nets were installed an increase in treetop growth, especially in the upper canopy, was seen. Bud break was also noted to be easier, or quicker, under nets, as grower A commented that lower dosages of oil and or Dormex applications were required compared to trees not under nets.

12. Did your pruning requirements change?

More summer pruning was required, while winter pruning dates were often a few days later compared to the trees not under nets. However, winter pruning loads were not out of the ordinary. Grower A expected 50% more vigor on all cultivars under nets. Grower B noted a strong increase in tree top growth in the first season after nets were installed, and winter pruning dates were postponed towards the bloom period to minimize regrowth as much as possible. Grower B also noted that trees under nets grew ca. 20 to 25% faster than those not under nets. Grower C could not yet comment on the new trees under nets. Grower D noted regrowth after pruning was faster and more intense under nets, and bud break was easier compared to trees not under nets.

13. How severe was the increase in vegetative growth under nets if you experienced this?

A 20-25% increase in vegetative growth was seen, with one grower expecting 50% more vigor, but warning signs to act accordingly are easier to interpret giving enough time to apply growth regulators or prune again.

QUESTIONS AND ANSWERS ON ENVIRONMENT UNDER NETS

1. Did you observe changes in bud break date and duration?

Bud break was found to be 2-3 days later, but occurred quicker, but not significantly so as to affect crops.

2. Did you observe a change in cover crop growth and is so, what??

No changes were seen in cover crop growth.

3. Did you notice any negative changes in bee activity during pollination, if so, what did you do to compensate for these changes?

Bee observations ranged from no changes to a slight increase in bee activity under nets as they could not escape reaching other food sources. Growers also noted it is important to ensure there is enough feed and water for the bees under the nets to prevent them from searching elsewhere. Some would provide food sources such as sucrose and sugar water bowls under nets when there are little to no flowering, to try keep the bees within the orchard.

4. Any other comments you would like to make?

Growers commonly noted that when trying to improve yield and or fruit quality, no single factor or variable can be looked at for manipulation, and the majority of the variables involved in yield and fruit quality cannot be exclusively controlled by one or two practices For example when trying to reduce physical damage with the use of nets, the tree growth and reproductive development are affected, as well as the water and nutrient requirements. Growth, in general, was more intense under nets. Wind damage can be quite devastating in the Western Cape, therefore nets have a major effect in reducing this. Some areas prone to hail and intense sunburn also obtain protection of fruit. One issue mentioned repeatedly was regarding sufficient pollination under nets as plums are self-incompatible and bees are highly influenced by their environment.

Conclusion

Western Cape plum growers installed nets as a means to protect their plum crop against wind and to a lesser extent, sunburn and hail damage. It took on average between 2 and 5 years to recover the costs of the nets, but the benefits of nets outweighed the initial capital burden, and thus the questioned growers highly recommended nets for long term protection against meteorological damage. The one older orchard saw an increase in plum yields, whilst the younger orchard saw a slight decrease in yield. When looking at the data we got in Paper 1 and 2, compared to the grower B's response in the questionnaire, it is clear that a slight decrease in yield was observed under nets in 'Midnight Gold', whilst 'Larry Ann;' either decreased or had no change in yield. A big advantage of the nets was that young trees filled their allotted spaces quicker. No problems were noted regarding return bloom or pollination under the nets. An increase in fruit size was one of the main positives seen under the nets, however, decreases of up to 20% were also observed but the pack-out percentage of high quality fruit was increased. A small advancement in harvest maturity was also found in the commercial harvest dates. The growers all commented that tree growth and development under nets become more complex.

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Fig. 1. Example of the net structure on farm A, where all sides are closed with green net, angled at 45°, and only a small section open at the main entrance for farm vehicles. (Photo: N. van Rensburg).

Fig. 2. Example of the entrance to the net structure on farm A. During very intense wind storms the entrance can be closed as well. (Photo: N. van Rensburg).

Fig. 3. Inside of the net structure at farm A. Shade net is a 20% crystal white blocking 20% UV and having a 6% shading factor. Nets were installed in 2018 for the main reason of wind protection. Cultivars include 'Black Pearl', 'Angeleno', 'Fortune', 'Laetitia', and 'Songold' all grafted onto Maridon rootstocks. (Photo: N. van Rensburg).

Fig. 4. Example of the permanent flat net structure at farm B, where all sides are open, and net is a 20% crystal white net covering 'August Yummy' and 'Midnight Gold' plums. (Photo: N. van Rensburg).

Fig. 5. Example of the open ends, and pole structuring of the net at farm B. (Photo: N. van Rensburg).

Fig. 6. Example of a black woven net, with a 20% shading factor set up as a retractable pointed structure over each row on farm C. (Photo: N. van Rensburg).

Fig. 7. Cultivar ‘Autumn Treat’ on Mariana rootstock at farm C, with the shade nets currently retracted / open. (Photo: N. van Rensburg).

Appendix A

FARM A

Research Questionnaire: Effect of protective nets on fruit quality and tree growth

Please answer the following questions as factually as possible, tick boxes where appropriate, and give short explanations where possible.

GENERAL QUESTIONS ABOUT THE FARM & NET SET UP

1. What was the most important reason(s) for putting up a net structure?

Wind protection, as well as hail protection. Mostly wind

2. Please describe the orchard set up (location of farm, cultivars, rootstock, soil type/vigor)

Bon Esperance Farm, Stellenbosch. All plum varieties on Maridon rootstock, all orchards planted 4.0m x 1.5m. Soil – plinthic soil with 14% clay content, 70cm deep, very suitable for stone fruit, medium vigor, varieties under nets = Black Pearls, Angeleno's, Fortunes, Laetitia, Songold, main reason for construction under

3. When did you construct the netting structure? (year)

2018

4. How old was the orchard when establishing the net structure?

4, years, 5 years, 6 years

5. How long did it take to break even the netting structure's costs?

	Less than one season or one year
	1 – 2 years / seasons
	2-3 years / seasons
	Other (please note time): Break-even is a calculation for the future, only recent construction

6. To what extent did you have to alter the general orchard practices with regards to the net structure, i.e. tree management/pruning, irrigation, fertilization, pollination?

No crop yet, but expecting lower fertilization rates, 10% lower irrigation, 30% more beehives/pollination costs, 30% more costs in terms of summer pruning

QUESTIONS ABOUT NET STRUCTURE

1. How large of an area is covered by the netting structure?

	Less than 1 Hectare		5 - 6 Hectares
	1 - 2 Hectare		7 – 8 Hectares
	3 - 4 Hectares		Other (please state) 15Ha

2. What type of netting structure have you installed?

	Flat structure, open ends		Retractable structure
x	Flat structure, closed on all sides		Gabled
	Flat structure, closed on 1 or 2		Draped
	Other:		

3. Is the structure retractable?
    a. If the net structure is retractable, when do you open and close the nets?

No opening or closing, flat structure

4. What color, type (woven/knitted) and shade percentage net have you used?

Class 20, removing 20% UV, 6% shade net, Crystal color

5. How much space if left between the tops of the trees and the net?

1.4m

QUESTIONS ABOUT FRUIT YIELD AND TREE GROWTH UNDER NETS

1. Did you experience an increase or decrease in overall yield per cultivar? List Different cultivars in top column if there is more than one and tick appropriate boxes and indicate approximate level of change in percentage.

No crop yet							
	Increase		Increase		Increase		Increase
	Decrease		Decrease		Decrease		Decrease
	No change		No change		No change		No change

2. What effect did the nets have on return bloom for each cultivar?

	Poor return bloom each season
	Increase in alternate bearing
	Increase in return bloom
	No noticeable pattern over seasons
	Other: No crops yet, no first-hand experience.

3. What changes did you see with regards to fruit size?

	Increase		Inconsistent results
	Decrease		No change

4. Sunburn/heat damage and/or wind damage effects?

	Reduced sunburn		No change in sunburn
	Reduced wind damage		No change in wind damage
	Reduced heat damage		No change in heat damage
	Other:		

5. What was the effect on harvest maturity?

	Advanced in TSS		No change in TSS
	Decrease in firmness		No change in firmness
	Advance color		No change in color
	Comments:		

6. Did you receive any feed-back on post-harvest fruit quality?

	Decreased internal browning		No change in internal browning
	Decreased gel breakdown		No change in gel breakdown
	Decreased chilling injury		No change in chilling injury
	Decreased heat damage		No change in heat damage

	Comments:

7. Comments on pack-out percentages per cultivar?

8. Did you receive a better income and indicate percentage change?

	Yes		No

9. Did you experience an increase or decrease in pest damage, and by how much?

	Increase		Decrease
By how much:			

10. Did you experience an increase or decrease in disease damage, and by how much?

	Increase		Decrease
By how much:			

11. Give a quick description of any major changes to tree growth?

12. Did your pruning requirements change?

Expecting 50% more vigor.

13. How severe was the increase in vegetative growth under nets if you experienced this?

QUESTIONS ON ENVIRONMENT UNDER NETS

1. Did you observe changes in bud break date and duration?

YES in Date		NO in Date	
YES in Duration		No in Duration	
Date:	Earlier by______ number of days	Later by _________number of days	
Duration:	Longer by______ number of days	Shorter by________ number of days	

2. Did you observe a change in cover crop growth and is so, what??

YES / NO

3. Did you notice any negative changes in bee activity during pollination, if so, what did you do to compensate for these changes?

YES / NO not yet

4. Any other comments you would like to make?

1st Season under nets coming up

FARM B

Research Questionnaire: Effect of protective nets on fruit quality and tree growth

Please answer the following questions as factually as possible, tick boxes where appropriate, and give short explanations where possible.

GENERAL QUESTIONS ABOUT THE FARM & NET SET UP

7. What was the most important reason(s) for putting up a net structure?

Wind damage

8. Please describe the orchard set up (location of farm, cultivars, rootstock, soil type/vigor)

Farm is located in the Overhex area just outside Worcester, WC.

9. When did you construct the netting structure? (year)

2016

10. How old was the orchard when establishing the net structure?

Midnight Gold & August Yummy in their 3rd leaf, Larry Ann in 4th leaf.

11. How long did it take to break even the netting structure's costs?

	Less than one season or one year
	1 – 2 years / seasons
x	2-3 years / seasons
	Other (please note time) New orchard

12. To what extent did you have to alter the general orchard practices with regards to the net structure, i.e. tree management/pruning, irrigation, fertilization, pollination?

Nutrient fertilization is reduced to try control vegetative growth, as growth is enhanced under the nets. Winter pruning dates postponed minimizing regrowth as much as possible. Irrigation is normal. More pruning done to create more light interception under nets.

QUESTIONS ABOUT NET STRUCTURE

6. How large of an area is covered by the netting structure?

	Less than 1 Hectare		5 - 6 Hectares
x	1 - 2 Hectare		7 – 8 Hectares
	3 - 4 Hectares		Other (please state)

7. What type of netting structure have you installed?

X	Flat structure, open ends		Retractable structure
	Flat structure, closed on all sides		Gabled
	Flat structure, closed on 1 or 2		Draped
	Other:		

8. Is the structure retractable?
   a. If the net structure is retractable, when do you open and close the nets?

9. What color, type (woven/knitted) and shade percentage net have you used?

20 % crystal white, Knitted

10. How much space if left between the tops of the trees and the net?

1 m

QUESTIONS ABOUT FRUIT YIELD AND TREE GROWTH UNDER NETS

14. Did you experience an increase or decrease in overall yield per cultivar? List Different cultivars in top column if there is more than one and tick appropriate boxes and indicate approximate level of change in percentage.

August Yummy		Midnight Gold		Larry Ann			
	Increase		Increase		Increase		Increase
X	Decrease (20%)	X	Decrease (5-10%)		Decrease		Decrease
	No change		No change	X	No change		No change

15. What effect did the nets have on return bloom for each cultivar?

	Poor return bloom each season
	Increase in alternate bearing
	Increase in return bloom
X	No noticeable pattern over seasons

16. What changes did you see with regards to fruit size?

X	Increase		Inconsistent results
	Decrease		No change

17. Sunburn/heat damage and/or wind damage effects?

X	Reduced sunburn		No change in sunburn
X	Reduced wind damage		No change in wind damage
	Reduced heat damage		No change in heat damage
	Other: Intensity of wind damage on Midnight Gold was decreased a lot.		

18. What was the effect on harvest maturity?

	Advanced in TSS	X	No change in TSS
	Decrease in firmness	X	No change in firmness
	Advance color	X	No change in color
	Comments: August Yummy peel color was delayed		

19. Did you receive any feed-back on post-harvest fruit quality?

	Decreased internal browning	X	No change in internal browning
	Decreased gel breakdown	X	No change in gel breakdown
	Decreased chilling injury	X	No change in chilling injury
	Decreased heat damage	X	No change in heat damage
	Comments:		

20. Comments on pack-out percentages per cultivar?

	More Class A, larger fruit with less damage

21. Did you receive a better income and indicate percentage change?

	Yes		No

22. Did you experience an increase or decrease in pest damage, and by how much?

	Increase		Decrease
By how much: NONE			

23. Did you experience an increase or decrease in disease damage, and by how much?

	Increase		Decrease
By how much: NONE			

24. Give a quick description of any major changes to tree growth?

Top growth was enhanced directly after the nets were installed

25. Did your pruning requirements change?

Winter pruning postponed until late in the bloom period to reduce regrowth as much as possible

26. How severe was the increase in vegetative growth under nets if you experienced this?

About 20-25% more vegetative growth

QUESTIONS ON ENVRIONMENT UNDER NETS

5. Did you observe changes in bud break date and duration?

YES in Date		NO in Date	X
YES in Duration		No in Duration	X
Date:	Earlier by______ number of days	Later by __________number of days	

Duration:	Longer by______ number of days	Shorter by________ number of days

6. Did you observe a change in cover crop growth and is so, what??

YES / NO NO

7. Did you notice any negative changes in bee activity during pollination, if so, what did you do to compensate for these changes?

NO

8. Any other comments you would like to make?

None

FARM C

Research Questionnaire: Effect of protective nets on fruit quality and tree growth

Please answer the following questions as factually as possible, tick boxes where appropriate, and give short explanations where possible.

GENERAL QUESTIONS ABOUT THE FARM & NET SET UP

13. What was the most important reason(s) for putting up a net structure?

1. Sunburn
2. Water saving efforts
3. Ice rain / hail

14. Please describe the orchard set up (location of farm, cultivars, rootstock, soil type/vigor)

1. Protea farm is situated in the Koo Valley 30km outside Montagu on the
2. Orchard planted in 2017.
Plum Autumn Treat. On Marianna

15. When did you construct the netting structure? (year)

2017

16. How old was the orchard when establishing the net structure?

Same time

17. How long did it take to break even the netting structure's costs?

	Less than one season or one year
	1 – 2 years / seasons
	2-3 years / seasons
X	Other (please note time) New orchard

18. To what extent did you have to alter the general orchard practices with regards to the net structure, i.e. tree management/pruning, irrigation, fertilization, pollination?

1. The growth in the first year equal to what we normally get in three years
2. My nets open during blossom, so I don't think anything unusual for the
3. Micro irrigation currently only 45min max at a time

QUESTIONS ABOUT NET STRUCTURE

11. How large of an area is covered by the netting structure?

	Less than 1 Hectare		5 - 6 Hectares
x	1 - 2 Hectare		7 – 8 Hectares
	3 - 4 Hectares		Other (please state)

12. What type of netting structure have you installed?

	Flat structure, open ends	x	Retractable structure
	Flat structure, closed on all sides		Gabled
	Flat structure, closed on 1 or 2		Draped
	Other:		

13. Is the structure retractable?
    a. If the net structure is retractable, when do you open and close the nets?

Open first week of May
Close end Oct

14. What color, type (woven/knitted) and shade percentage net have you used?

Black, Woven, <20%

15. How much space if left between the tops of the trees and the net?

1.5m

QUESTIONS ABOUT FRUIT YIELD AND TREE GROWTH UNDER NETS

27. Did you experience an increase or decrease in overall yield per cultivar? List Different cultivars in top column if there is more than one and tick appropriate boxes and indicate approximate level of change in percentage.

N/A							
	Increase		Increase		Increase		Increase
	Decrease		Decrease		Decrease		Decrease
	No change		No change		No change		No change

28. What effect did the nets have on return bloom for each cultivar?

	Poor return bloom each season
	Increase in alternate bearing
	Increase in return bloom
	No noticeable pattern over seasons
	Other: 2019 will be first harvest under nets

29. What changes did you see with regards to fruit size?

	Increase		Inconsistent results
	Decrease		No change

30. Sunburn/heat damage and/or wind damage effects?

	Reduced sunburn		No change in sunburn
	Reduced wind damage		No change in wind damage
	Reduced heat damage		No change in heat damage
	Other:		

31. What was the effect on harvest maturity?

	Advanced in TSS		No change in TSS
	Decrease in firmness		No change in firmness
	Advance color		No change in color
	Comments:		

32. Did you receive any feed-back on post-harvest fruit quality?

	Decreased internal browning		No change in internal browning
	Decreased gel breakdown		No change in gel breakdown
	Decreased chilling injury		No change in chilling injury
	Decreased heat damage		No change in heat damage
	Comments:		

33. Comments on pack-out percentages per cultivar?

34. Did you receive a better income and indicate percentage change?

	Yes		No

35. Did you experience an increase or decrease in pest damage, and by how much?

	Increase		Decrease
By how much:			

36. Did you experience an increase or decrease in disease damage, and by how much?

	Increase		Decrease
By how much:			

37. Give a quick description of any major changes to tree growth?

38. Did your pruning requirements change?

39. How severe was the increase in vegetative growth under nets if you experienced this?

QUESTIONS ON ENVRIONMENT UNDER NETS

9. Did you observe changes in bud break date and duration?

YES in Date		NO in Date	
YES in Duration		No in Duration	

Date:	Earlier by______ number of days	Later by _________number of days
Duration:	Longer by______ number of days	Shorter by________ number of days

10. Did you observe a change in cover crop growth and is so, what??

YES / NO

11. Did you notice any negative changes in bee activity during pollination, if so, what did you do to compensate for these changes?

NO, net s are open

12. Any other comments you would like to make?

Amazing growth in first year.

FARM D

Research Questionnaire: Effect of protective nets on fruit quality and tree growth

Please answer the following questions as factually as possible, tick boxes where appropriate, and give short explanations where possible.

GENERAL QUESTIONS ABOUT THE FARM & NET SET UP

19. What was the most important reason(s) for putting up a net structure?

Sunburn
Wind
Water

20. Please describe the orchard set up (location of farm, cultivars, rootstock, soil type/vigor)

Wellington Area, R45, (33˚35'58.16" S, 18˚55'40.55 E)
AFI, AFD, AFP, AFG, ANG, AP1, BDI, FRT, LAE, LAN, LDR, RBA, RUY,
Plums rootstock mostly Mariaan and nectarine rootstock, Kakamas.
Heavy clay soil
Medium vigor

21. When did you construct the netting structure? (year)

2016

22. How old was the orchard when establishing the net structure?

8 years

23. How long did it take to break even the netting structure's costs?

	Less than one season or one year
	1 – 2 years / seasons
	2-3 years / seasons
5	Other (please note time)

24. To what extent did you have to alter the general orchard practices with regards to the net structure, i.e. tree management/pruning, irrigation, fertilization, pollination?

Earlier summer pruning, keeping regrowth shorter.
Better water retention

Less nitrogen fertilization.
Bees worked good under nets. Make sure they have enough water and feed them when
there are not many flowers (food)

QUESTIONS ABOUT NET STRUCTURE

16. How large of an area is covered by the netting structure?

	Less than 1 Hectare		5 - 6 Hectares
	1 - 2 Hectare		7 – 8 Hectares
	3 - 4 Hectares	43	Other (please state)

17. What type of netting structure have you installed?

	Flat structure, open ends		Retractable structure
√	Flat structure, closed on all sides		Gabled
	Flat structure, closed on 1 or 2		Draped
	Other:		

18. Is the structure retractable?

    a. If the net structure is retractable, when do you open and close the nets?

No

19. What color, type (woven/knitted) and shade percentage net have you used?

20% White, woven

20. How much space if left between the tops of the trees and the net?

1.2m

QUESTIONS ABOUT FRUIT YIELD AND TREE GROWTH UNDER NETS

40. Did you experience an increase or decrease in overall yield per cultivar? List Different cultivars in top column if there is more than one and tick appropriate boxes and indicate approximate level of change in percentage.

Ruby Sweet		African Delight		African Rose			
13	Increase	8.5	Increase		Increase		Increase
	Decrease		Decrease		Decrease		Decrease

	No change		No change	√	No change		No change

41. What effect did the nets have on return bloom for each cultivar?

	Poor return bloom each season
	Increase in alternate bearing
	Increase in return bloom
	No noticeable pattern over seasons
√	Other: No negative effect, maybe just few days later

42. What changes did you see with regards to fruit size? RSW

	Increase		Inconsistent results
	Decrease		No change

Ruby Sweet

		Oop	Onder nette
Blok no		58, 100.2	89, 90
Ha		3.08	4.07
Ton/ha		17.3	17.8
Toename in klas1 uitvoer			13%
Size vgl	23 en groter	11.8%	22.1%
	25 en groter	40.9%	53.5%
	28 en groter	80.4%	83.5%
Suiker	A	12.1	12.6
	B	11.9	12.0
	C	11.5	10.9

43. What changes did you see with regards to fruit size? AFD

√	Increase		Inconsistent results
	Decrease		No change

	Onder net	oop
AAAA	7.1%	5.0%
AAA	25.1%	23.3%
AA	31.7%	31.6%
A	22.0%	22.2%
B	12.6%	15.1%
C	1.1%	1.8%
under	0.4%	1.0%

44. Sunburn/heat damage and/or wind damage effects? RSW + AFD

√	Reduced sunburn		No change in sunburn
√	Reduced wind damage		No change in wind damage
√	Reduced heat damage		No change in heat damage
	Other:		

45. What was the effect on harvest maturity? RSW

	Advanced in TSS	√	No change in TSS
	Decrease in firmness		No change in firmness
√	Advance color		No change in color
	Comments: Little firmer under nets		

46. What was the effect on harvest maturity? AFD

	Advanced in TSS	√	No change in TSS
	Decrease in firmness	√	No change in firmness
√	Advance color		No change in color
	Comments:		

47. Did you receive any feed-back on post-harvest fruit quality? RSW + AFD

	Decreased internal browning	√	No change in internal browning
	Decreased gel breakdown	√	No change in gel breakdown
	Decreased chilling injury	√	No change in chilling injury
	Decreased heat damage	√	No change in heat damage

	Comments:

48. Comments on pack-out percentages per cultivar?

RSW	13% more class 1 export
AFD	8.4% more class 1 export

49. Did you receive a better income and indicate percentage change?

	Yes		No, same price per carton

50. Did you experience an increase or decrease in pest damage, and by how much?

	Increase		Decrease
By how much: Not significant			

51. Did you experience an increase or decrease in disease damage, and by how much?

	Increase		Decrease
By how much: Not significant			

52. Give a quick description of any major changes to tree growth?

Get more regrowth after pruning Seems like we are getting easier breaks

53. Did your pruning requirements change?

Yes, can prune timeously and as we like. Must prune more.

54. How severe was the increase in vegetative growth under nets if you experienced this?

It is more, but you do get an early warning and there is enough time to react with taking away fertilizer and pruning

QUESTIONS ON ENVRIONMENT UNDER NETS

13. Did you observe changes in bud break date and duration?

YES, in Date	later	NO in Date	
YES in Duration		No in Duration	√
Date:	Earlier by______ number of days	Later by ___2-3______number of days	
Duration:	Longer by______ number of days	Shorter by________ number of days	

14. Did you observe a change in cover crop growth and is so, what??

YES / NO

We do not give water to the cover crop, but it lasts longer before drying.

15. Did you notice any negative changes in bee activity during pollination, if so, what did you do to compensate for these changes?

YES / NO

Nets must either be open, or totally (sides also) closed while bees in.

If they manage to get out, most get stuck on the outside trying to get back inside.

Feed the bees when flowers are few.

Make sure there is enough water near the hives.

16. Any other comments you would like to make?

Appendix B

Introductory letter regarding my research questionnaire, as well as permission to use data obtained for my research paper.

Title of research questionnaire: Effect of protective nets on fruit quality and tree growth

Dear Grower,

I, Nasreen van Rensburg, from the Department of Horticultural Sciences at Stellenbosch University, Stellenbosch, require additional information from local plum growers that have made, or make use of protective nets over their orchards. The research project is for the partial fulfilment for a Master's Degree in AgriSciences, which will consist of three scientific papers, one which will be the findings of this questionnaire. The project entails the impact of protective nets on two Japanese plum cultivars, 'Larry Ann' and 'Midnight Gold' tree productivity, yield and fruit quality. The trial site of my project is on farm in the Robertson-Worcester area, in the Western Cape.

In order to get a general overview, I have set up a questionnaire regarding the mechanics of the type constructed over your orchard(s), as well as questions regarding the effects it has had on yield and fruit quality. I would sincerely appreciate if you answer the questions as factually as possible, and if by any means you cannot answer a specific question, you may leave it blank. I will not publish or disclose any personal information to the public, and your identity as well as the farm's identity will remain completely anonymous. To get an understanding of environmental effects, or growing region trends, the farm location will be required (nearest town/geographical area), however you will not be required to give the name of the farm.

Lastly, in order to publish the data as findings from a questionnaire and or interviews, I will require your signature on this document, which will serve as both permission to use the information for my research, as well as that the information you provided is as factually correct as possible.

If you would like more information regarding my research, please do not hesitate to contact me, or my supervisor Professor K. Theron. Once the research project is complete, it will be published in my thesis and be open to public viewing. If you would like a copy of the final paper regarding the questionnaire findings, please feel free to email us and we will send you the link of the online publication.

Kind Regards

Nasreen van Rensburg
MSc Student, Stellenbosch University
Email: 17051827@sun.ac.za

Professor Karen I Theron
Project supervisor
Stellenbosch University
Email: kit@sun.ac.za

GROWER A

Your Signature

AUGUST 2018

Date

Introductory letter regarding my research questionnaire, as well as permission to use data obtained for my research paper.

Title of research questionnaire: Effect of protective nets on fruit quality and tree growth

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Kind Regards

Nasreen van Rensburg
MSc Student, Stellenbosch University
Email: 17051827@sun.ac.za

Professor Karen I Theron
Project supervisor
Stellenbosch University
Email: kit@sun.ac.za

GROWER B

Your Signature

AUGUST 2018

Date

Introductory letter regarding my research questionnaire, as well as permission to use data obtained for my research paper.

Title of research questionnaire: Effect of protective nets on fruit quality and tree growth

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Kind Regards

Nasreen van Rensburg
MSc Student, Stellenbosch University
Email: 17051827@sun.ac.za

Professor Karen I Theron
Project supervisor
Stellenbosch University
Email: kit@sun.ac.za

GROWER C

Your Signature

2018/09/30

Date

Introductory letter regarding my research questionnaire, as well as permission to use data obtained for my research paper.

Title of research questionnaire: Effect of protective nets on fruit quality and tree growth

Dear Grower,

I, Nasreen van Rensburg, from the Department of Horticultural Sciences at Stellenbosch University, Stellenbosch, require additional information from local plum growers that have made, or make use of protective nets over their orchards. The research project is for the partial fulfilment for a Master's Degree in AgriSciences, which will consist of three scientific papers, one which will be the findings of this questionnaire. The project entails the impact of protective nets on two Japanese plum cultivars, 'Larry Ann' and 'Midnight Gold' tree productivity, yield and fruit quality. The trial site of my project is on farm in the Robertson-Worcester area, in the Western Cape.

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If you would like more information regarding my research, please do not hesitate to contact me, or my supervisor Professor K. Theron. Once the research project is complete, it will be published in my thesis and be open to public viewing. If you would like a copy of the final paper regarding the questionnaire findings, please feel free to email us and we will send you the link of the online publication.

Kind Regards

Nasreen van Rensburg
MSc Student, Stellenbosch University
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Professor Karen I Theron
Project supervisor
Stellenbosch University
Email: kit@sun.ac.za

GROWER D

Your Signature

AUGUST 2018

Date

General Discussion and Conclusion

The available literature on shade nets used for fruit production focuses on mainly deciduous fruit, while less information is available for citrus, berries, and stone fruit, specifically plums. Japanese plums are cultivated mainly in warmer regions as their chilling requirement is low and the trees bloom early in the season, and as the flowers are highly sensitive to winter and spring frost, making warmer regions more suitable for plums (Hartman and Neumüller, 2009). Plum production in South Africa is relatively low compared to other deciduous fruit, but South Africa is listed as the second-largest exporter of plum fruit, with an annual turnover of around R2,7 billion (Hortgro, 2017), thus finding ways to reduce fruit losses, and or improve production quality, is highly beneficial to the industry. Plum orchards in the Western Cape are often affected by wind, sunburn, hail and frost damage throughout the seasons and thus many growers have invested in net structures (Paper 3). The most common net structures used in Japanese plum orchards in the Western Cape are permanent flat structures, with two or more sides closed to reduce wind as much as possible, while the shading percentages range from 6 to 20% reducing incident radiation and thus sunburn. In some parts of the Western Cape, hailstorms are problematic during the winter and or early spring causing damage to both trees and fruit. One of the growers opted for a gabled, retractable structure that is opened during winter to allow any hail to fall to the ground and closed after fruit set for damage protection (Paper 3).

In Paper 1, the shade nets effectively reduced wind damage to both ‘Midnight Gold’ and to a lesser degree, ‘Larry Ann’ plums, while the percentage and severity of sunburnt fruit was low over both seasons. The severity and amount of wind damage on ‘Midnight Gold’ were significantly reduced under nets with a ca. of 1% reduction in the first season and a ca. of 20% reduction in the second season. The total yield and fruit size of ‘Larry Ann’ was reduced under the nets in season one, while for ‘Midnight Gold’ yield was reduced in season two. Both cultivars harvested from under the nets were also less firm at harvest in the second season, but after cold storage the differences in firmness between treatments were commercially insignificant. Furthermore, the degree of color differences between netted and non-netted fruit remained throughout cold storage, with netted fruit being slightly darker red and or purple than non-netted fruit due to reduced chroma and lightness, but these small yet significant differences would not have been noticed by the consumer. Furthermore, the postharvest quality of the netted fruit was maintained better during cold storage and experienced fewer internal disorders. The differences in fruit maturity between the netted fruit and the controls were also seen during cold storage, with controls leading in maturity having higher total soluble solid (TSS) concentrations, lower total acidity (TA) and delayed red color development. The more mature controls therefore had higher percentages of gel breakdown, while the netted fruit had higher percentages of internal browning. However, after one week at shelf life conditions, both the controls and netted fruit had high percentages of decay. 'Larry Ann' plums experienced more internal disorders, while 'Midnight Gold' were more susceptible to decay.

Our main objective in Paper 2 was to reduce shoot growth under nets using the plant growth regulators (PGRs) paclobutrazol (PBZ), uniconazole (UCZ) and prohexadione-calcium (ProCa), all of which act by inhibiting gibberellin biosynthesis responsible for cell elongation. The foliar PGR treatments were ineffective in our trials, and only in the second season after the soil treatments with UCZ applied at flowering, and the lower PBZ applied after harvest the previous season, was the summer pruning reduced. With the vegetative growth being unaffected, we did not expect big changes in yield, however, both PBZ and UCZ treatments resulted in larger fruit in the first season. Fruit size is indirectly influenced by PGRs as vegetative growth decreases, more carbohydrate reserves would potentially be available for fruit, however in our trials, the treatments seldom reduced vegetative growth, but fruit thinning occurred as well as some increases in fruit size. The low efficacy on vegetative growth, and rather a stronger fruit thinning effect, could be explained by cultivar differences, and would be of interest to further study.

Thinning requirements were effectively reduced in 'Larry Ann' following foliar ProCa applications applied at bloom, whilst soil application of PBZ after harvest and UCZ applied at bloom reduced the thinning requirements of 'Midnight Gold'. Yield was increased in 'Larry Ann' following the double PBZ applications at PD plus four weeks later, whilst 'Midnight Gold' yield was not affected by foliar PGRs. Soil applied UCZ at bloom increased 'Midnight Gold' yields in the second season, but soil PGRs did not affect 'Larry Ann' yields. Foliar applied PGRs increased fruit size in both cultivars, while soil applied PBZ resulted in larger fruit in 'Larry Ann'. A final remark on the PGR trials would be to apply higher concentrations or additional applications in the following spring in future trials for vegetative growth control.

In conclusion, shade nets prevented physical damage to the plum peel with emphasis on reducing scuff marks due to wind damage, however, the reductions in yield were of concern. One option for future growers looking to make use of shade nets is to invest in retractable structures to allow sufficient light into the canopy during later fruit developmental stages for complete color development. Vegetative growth increases under shade nets, and the use of PGRs are sensitive to both the application timing and the rate when trees are more vigorous. The concentrations we had used were more effective in reducing the hand thinning requirements rather than the pruning requirements, but in most cases fruit size was increased without negative effects on yield.

Literature Cited

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